METHODS IN PALEONTOLOGY

CHARLES L. CAMP
AND
G. DALLAS HANNA

Arthur W. Pollister
March, 1939

CLUES
QE718.C3 CC CS
CAMP, CHAR METHODS [redacted]

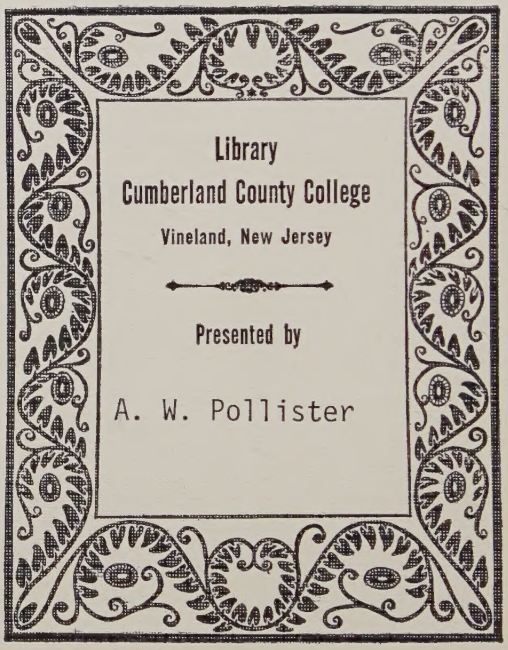
82-35

QE
718 Camp, Charles Lewis.
C3 Methods in paleontology.

JUL 2000
JUN 2004
JUL 09
JUL X X 2015

WITHDRAWN

Due Date Due Date Due Date Due Date Due Date Due Date


Library
Cumberland County College
Vineland, New Jersey
Presented by
A. W. Pollister

METHODS IN PALEONTOLOGY

Preparator Charles Christman at work on primitive reptiles in sandstone

METHODS IN PALEONTOLOGY

CHARLES L. CAMP AND
G. DALLAS HANNA

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA
1937

Cumberland County College
Library
P.O. Box 517
Vineland, NJ 08360

QE
701
C3

82-35

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA

CAMBRIDGE UNIVERSITY PRESS
LONDON, ENGLAND

COPYRIGHT, 1937, BY THE
REGENTS OF THE UNIVERSITY OF CALIFORNIA

PRINTED IN THE UNITED STATES OF AMERICA
BY SAMUEL T. FARQUHAR, UNIVERSITY PRINTER

CONTENTS

PAGE

Introduction ix
What is a fossil? xi
Where do fossils occur? xiii
History of fossil collecting xv
Outfits for expeditions xvii

PART ONE: VERTEBRATES

Field Methods 1
Prospecting for fossils 1
Excavating 5
Tools and equipment 6
Method of jacketing specimens 10
Numbering specimens 24
Shipping specimens 27
Laboratory Methods 28
Tools and equipment 28
Preparation of specimens 32
Modeling 40
Casting 41
Drawing 47
Photography 49
Sectioning of bones, teeth, and wood 52
Serial sectioning 53
Cataloguing 55
Storage 58
Use of material 59
Exhibits 60

[Note on Paleobotanical Collecting] 72

PART TWO: INVERTEBRATES

Preface 77
The collection and preparation of fossil invertebrates 79
Macrofossils 79
Unaltered sediments—Shales and soft sands—Hard sandstone—Hard shales and slates—Hard limestones
Tools and equipment 88
Microfossils 91
Foraminifera and Ostracoda—Diatoms, Radiolaria, etc.—Thin sections and polished surfaces—Pollen—Scales and otoliths of fishes—Conodonts and polychaetes
Bibliography 133
Index 151

INTRODUCTION

Fossils, long buried in the earth, tell the story of past life. They are objects which require careful collecting and preservation if they are to be used in deciphering the records. The search for fossils and reading of these "minutes of the past" is like detective work, fascinating to the devotees of paleontology; for the greater part of the fossil story still remains to be discovered and studied.

Knowledge of geology, zoölogy, and anatomy is fundamental to an understanding of the fossil evidence. The occurrence of the specimen—the rock in which it lies, the manner of its burial, and its association with other remains, both plant and animal—must be carefully recorded when a fossil is removed from its age-old resting place in the earth's crust.

Every museum contains sad examples of hastily collected and poorly prepared fossil material. Sometimes these broken specimens are irreplaceable, and similar ones will perhaps never be found again. Through ignorance or carelessness, the collector may in a few moments destroy or damage an object of scientific importance. Or an untrained preparator in the laboratory may remove valuable parts of a specimen along with the surrounding matrix. The care and caution necessary in the handling of many kinds of fossils can scarcely be imagined unless one has had field experience or other means of understanding the many problems involved. Consequently, no one should attempt to dig out a fossil unless he is certain that in so doing he will cause no damage to the specimen. Some of the methods of handling delicate fossils will be discussed in this manual—if for no better purpose than to show the great difficulties that confront anyone who attempts to excavate and prepare these fragile remains.

The collector plays an exacting rôle, since he is responsible for the condition of the material when it reaches the laboratory. He should therefore learn the methods of fossil collecting under the guidance of an experienced field man,

preferably in an organized field party. The precious records of past life deserve the utmost care in their handling and preservation. They should never be entrusted to a person who does not appreciate their meaning and value.

An experienced collector may spend days or even weeks in getting out material that could easily be taken up in fragments in a few hours. A careless person, reckless in his ardor, may be tempted to dig out a fossil hastily, to examine and rejoice over it. In so doing, he may ruin the specimen or so damage it that months of work in the laboratory will be required to piece together the shattered remnants. A fossil has indeed to be a stout object to withstand excited attacks from shovels, claw hammers, tire irons, crowbars, or other crude implements. If it survives the ordeal, it may prove to be a concretion or pseudofossil—one of the many "dinosaur eggs," petrified turtles, snakes, hearts, brains, or pumpkins so often treasured by the credulous.

Methods differ according to the nature of the material. Field problems are never exactly alike and it is often possible to gather up presentable specimens without taking special precautions. In some localities great collections of surface and quarry material have been obtained in this way. Such famous amateurs as Hugh Miller, the Scottish stonemason, and Andrew Geddes Bain of South Africa, were able to collect most of their finds without difficulty. But those who go over the same ground today can save more material by employing modern methods.

Future progress in paleontology will also partly depend upon information from persons unacquainted with field technique. But it is imperative that the collector should know what not to do, and whom to notify when discoveries are made. It is necessary that the study of a specimen should begin where it lies in place in the rock. And it should not be removed before its exact position in the rock strata is established and recorded. This applies particularly to human remains; subsequent artificial burial may have taken place.

The information outlined in this manual should be of interest not only to paleontologists, but also to field students of anthropology and geology who may find it desirable to employ paleontological methods on their own material. So we have mentioned some things which will seem trivial to the trained paleontologist but may nevertheless be useful to workers in related fields.

Many of the methods here described are commonly employed and have stood the test of experience. Very few can be called innovations. Some of the simpler and more useful processes were discovered years ago by workers whose names have not been recorded, so we do not attempt to give credit for the invention of all methods. Nor can we fully acknowledge our debt to colleagues who have given us information and advice. We are especially grateful to Messrs. Barnum Brown, Charles Christman, E. L. Furlong, Bernhard Hauff, C. J. Hesse, R. A. Stirton, Albert Thompson, and S. P. Welles; and to Drs. Ferdinand Broili, Robert Broom, Walter Granger, Friedrich von Huene, William Janensch, W. D. Matthew, F. R. Parrington, Bernhard Peyer, Erik A:son Stensiö, and V. L. VanderHoof. We are very grateful also to the John Simon Guggenheim Foundation, for a traveling fellowship which enabled Dr. Camp to visit museums in this country and abroad and to see at first hand the methods employed.

The drawings in the vertebrate section of this manual have been made by Mr. Owen J. Poe. The Works Progress Administration has given stenographic and photographic assistance.

What Is a Fossil?

Until about two hundred years ago any buried product of the earth, produced in ages past, was called a fossil. The word was applied to specimens such as rock samples, crystals, and minerals, as well as to organic remains. Even today the geologist may speak of fossil glaciers, sand dunes, stream channels, mud cracks, and lava flows. The anthropologist studies

"fossil" sites containing "fossil" cultures of early man—"fossil" hearths, implements, burials, and middens. Perhaps the word most frequently enters ordinary speech in its picturesque and figurative meanings. Attempts have been made to confine the useful term, fossil, in a strict definition having reference to things representing the life of past ages. Under this view, a fossil is any trace, track, impression, mold, cast, remnant, or any material part of a living thing which existed before the advent of Recent man. Such a fossil need not be petrified, mineralized, or otherwise altered in its original form or content. It is even possible to regard some bacteria as living fossils if they be found in ancient rocks, in the waters enclosed in crystals, or in stony meteorites dating from past geologic eras. Not always does a fossil represent an extinct organism, since many Recent organisms lived also in the ancient world. Nor can the remains of extinct animals and plants always be considered as fossils; for the dodo, the moa, the great auk, and the Steller sea cow have only recently become extinct, and their remains occur in the Recent period.

Sometimes it is impossible to determine the geologic age of specimens which may or may not be concurrent with Recent man. It is believed that animal types which occurred in the Pleistocene in Europe and Asia may be associated with modern man in some of the later deposits of North and South America. Hence, the strict definition of a fossil cannot always be applied.

Among the commonest of fossils are oil, coal, and natural gas—the "fossil fuels" basic to modern industrial society. In the search for oil, the geologist may employ another class of common fossils—the skeletons of microscopic organisms (diatoms and protozoans) and mollusks. Climatic conditions of the past are reconstructed by means of plant fossils—frond, leaf, flower, pollen, seed, or fruit impressions, as well as petrified trunks, stems, fibers, husks, nuts, and cones.

Profoundly interesting is the evidence given by fossils, in the study of the history of life. The most precious materials

for this purpose are the rare articulated skeletons and skulls of backboned animals. These are among the most difficult of fossils to find and to collect. The progress of exploration, of geological surveys, of transportation facilities, and of the mechanical means of excavation add rapidly to the discoveries. The most extensive contributions to knowledge are made by experienced collectors who go into the field with the express purpose of obtaining what the earth has to yield.

Where Do Fossils Occur?

A world of fossils surrounds us: embedded in the rocks, floating in the air, and suspended in the water. Building stones, bricks, marble slabs, and asphalt paving contain them. Diatomaceous dust, sediment from fossil-bearing rocks, leaf impressions, tracks, fragments of shells, are among the commonest of objects. Your cellar may have been dug in a bed of fossil shells. The concrete and plaster of your house doubtless contain fragments of past life. The chalk in your tooth paste may be made up of thousands of tiny shells. The amber of your pipe stem or necklace, itself fossil resin, may enclose the remains of insects which lived millions of years ago. Hundreds of fossil products of coal and diatomaceous earth—paraffin, aniline dyes, synthetic drugs, and resins—are in constant use. The atmosphere of city streets is permeated with fossil gases from fossil fuels.

A fossil may remain a mere curiosity if we do not know the time and place at which it lived. For scientific purposes it is necessary, then, to gather fossils from the rocks in which they were laid down and to understand the mode of deposition, the structure, and the positions of these strata in the earth's crust. Furthermore, the nature of the rock matrix may indicate the conditions under which the fossils once lived. Some rocks are produced by organisms; some are made up of their skeletons.

Rocks such as lavas, granites, schists, and slates which have been molten or violently altered usually contain little or no

record of life. Rocks which were laid down before hard-shelled organisms came into existence are also barren. Rocks which have suffered decay, weathering, or abrasion, such as ordinary soils, windblown sands, and glacial detritus, will usually disclose only the most resistant of fossil materials.

Fossils are generally found in the finer-grained sedimentary rocks deposited by wind and water. Coarse gravels and conglomerates, bedded down by swift waters or on surf-swept shores, sometimes contain bones and shells in small fragments, ground until unrecognizable in the pebble mill. Sandstones, shales, limestones, and water-laid tuffs or volcanic ash deposits are the rocks in which they most frequently occur. In sandstone or loose sand, bones are often scattered and encased in hard crusts of iron oxide or pyrites, and are usually uncrushed. In shale or mudstone, the bone is likelier to be clean or encased in softer gypsiferous or calcareous nodules, and is frequently crushed. In limestone the preservation is often exceedingly good—the preparation usually difficult. In tuff (volcanic ash beds) the bone is generally hard, siliceous, brittle, and well preserved. Rogers (1924) gives analyses of the composition of fossil bone.

Extraordinary kinds of sedimentary and organic deposits—glacial ice, frozen ground, cave dust and travertine, fossil amber, lignite and peat, oil springs, and asphalt pools—have yielded treasures of excellently preserved remains. The greatest discoveries of this sort have been made accidentally, rather than by systematic search.

In ice or frozen ground, leaves, insects, and mammals are sometimes preserved in cold storage. The wild tribes of Siberia gather fossil ivory and occasionally feast on frozen mammoth flesh from the tundras of the North. Miners along the Yukon have uncovered elephant, horse, and bison remains in the frozen ground, where decaying hair, flesh, and horny parts of these animals cause a stench to arise from the artificially thawed gold placers.

Chinese coolies laboring in the dank caves of Szechuan

excavate the bones of extinct hyenas, rhinoceroses, and other animals, to be ground up for "medicine." The first fossil human tooth from Asia was purchased in a Chinese drug-store.

Irish peasants, cutting bricks of fuel from their ancient peat bogs, have uncovered most of the known specimens of the giant elk. A Spanish botanical explorer in 1792 first noticed bones in the asphalt springs at Rancho La Brea, in southern California.

Fossils have appeared, unexpectedly, in the drill cores of oil wells from thousands of feet below the surface; from dredging and hydraulic operations; in road work, quarries, mines, tunnels, gravel pits, pipe-line trenches, wells, railway cuts, canals and other excavations. Sometimes they crop up in drained swamps and dry lake beds, and from beneath shifting sand dunes.

The collector will often find himself well repaid by watching excavating operations in his vicinity, questioning the workmen, and examining the material coming onto the dumps. The most important discoveries of remains of primitive man have been made in travertine and gravel quarries.

History of Fossil Collecting

Leonardo da Vinci, four hundred and fifty years ago, studied the nature and meaning of organic fossils. He arrived at logical conclusions mainly because he excavated his own material and thereby came to understand the conditions under which fossils are laid down and preserved. By means of field work he devised a method of deciphering the history of the earth and particularly of the life upon it.

Unfortunately, the possibilities of this method were but little appreciated during the next three centuries. Fossil specimens were treated as curios or placed in cabinets of Natural History with some slight effort to arrange, classify, and describe the material under so-called scientific names. Not until Cuvier's time were fossils again seriously studied

in their relations to geology and biology. Cuvier's results were based on the first great collections ever systematically made in one place—the stone quarries of the Paris Basin.

In America, fossil hunting gradually followed the expanding frontier. The first organized collecting was directed by Thomas Jefferson. He employed Captain William Clark, who had just returned from the Lewis and Clark expedition, to excavate the bones of extinct elephants and bison so abundant in Kentucky's Big Bone Lick. The fossils, fortunately easy to handle and prepare, were sent to the White House and spread out on a large table where they were studied by Caspar Wistar and by Jefferson himself.

Jefferson's interest in westward expansion, culminating in the exploration of the Louisiana Purchase, stimulated American enterprise in the Rocky Mountain region. Trappers, penetrating to the headwaters of the Cheyenne River in the early 'twenties, discovered the petrified cycad "forests" of the Black Hills. They also brought back petrified bones and stories of "peetrified birds singing peetrified songs."

The military occupation of the plains, with the establishment of permanent posts, led to further discoveries by the soldiers. Officers stationed at Fort Bridger sent bones from the badlands to the great naturalist Joseph Leidy. The American paleontologists O. C. Marsh and E. D. Cope and the government surveying expeditions ardently took up the field work, and their collectors in the 'seventies invented the modern technique of fossil hunting and collecting.

Field parties from Yale, the Carnegie Museum, the National Museum, and the American Museum of Natural History were particularly active in improving the methods of collecting. Two men should especially be mentioned: Jacob Lawson Wortman and John Bell Hatcher, who, under O. C. Marsh, employed plaster and flour-paste bandages and shellac in the field. Hatcher, in his younger days, was a coal miner; a man of great enterprise and ingenuity, he later became a leader in scientific paleontology. Some of their contemporaries and

successors who became distinguished are C. H. Sternberg, Paul Miller, Albert Thompson, A. S. Coggeshall, O. C. Peterson, C. W. Gilmore, Barnum Brown, and Walter Granger. It is to such skilled collectors as these that we owe the magnificent collections now to be found in our museums.

In the past thirty years, American, English, German, French, Scandinavian, Russian, and Dutch expeditions have gone to remote regions seeking evidences of primeval life. Manifestly, their discoveries have given us much of what is known; yet their methods of uncovering and handling fragile specimens have seldom been fully published.

Outfits for Expeditions

Almost all fossil districts in North America are now approachable by motor transport, with the exception of some parts of Alaska, Canada, Utah, and Mexico. The type of automobile used will depend upon the size of the party, the distance and nature of the country to be traversed, and the size and weight of the specimens to be transported. It is usual to plan the hauling of specimens to the nearest point on a railroad or commercial truck line and to ship from there by freight or express.

For a party of three or fewer, a quarter-ton or half-ton truck equipped preferably with an enclosed or screen body, or enclosed cab, and oversized balloon tires (air tires or traction tires in sandy regions) will usually suffice. The tires should be new and two spares should be carried. A short wheel base, and good clearance both under the axles and behind the rear wheels, are great advantages when cross-country driving is done off the roads. For a larger party it is better to take two or more cars than to depend on one big truck. The "station-wagon" type of light car will carry a sizable number of persons, and at least one other truck will then be necessary for the equipment. It may be noted that the station-wagon seats are removable and the car can then be used as a truck. If expenses must be kept down, a good second-

hand seven-passenger sedan of the Cadillac or Lincoln type may suffice. Many of these cars, originally sold in the period 1923–1929, now bring as little as one-fiftieth of their original cost. They have high clearance, are of sturdy construction, and will carry up to a ton of load. Some of them have a tire pump working off the engine, a convenience for inflating tires or air mattresses in camp or on the road. A disadvantage of many of the newer models is that the frame and body have been lowered and the rear end extended so far as to prohibit driving over rough country away from the roads. At least two manufacturers, however, will now provide light cars with extra-large wheels to increase road clearance.

If an open-bodied truck is selected, a canvas tarpaulin or wagon cover may be roped over the load to protect it from dust and rain. Tire chains, fire extinguisher, a full set of tools (jack, pump, tire irons, etc.), tire-patch outfit, extra spark plugs, head and tail lights, fan belt, rope, wire, nails, hatchet, saw, hammers, and axe are sometimes necessary. Lacking chains, ropes may be wrapped around the tires for short hauls on muddy or sandy roads. The rope should be kept away from the valve stem of the tire. A long-handled shovel and an axe should be carried in an accessible place—this is the law in many forest reserves in the United States, because of forest fires.

In arid regions it is advisable to have containers for carrying and storing water. When traveling is done through sand in hot weather the radiator may need replenishing, to say nothing of the occasional necessity of making a dry camp. Gallon and half-gallon canteens covered with wet sacking can be used for drinking water. Larger two- to five-gallon containers may be strapped to the running board, and milk cans, barrels, or empty gasoline drums may be used for the camp supply or at quarry sites.

It is rarely necessary to provide extra gasoline, as service stations are numerous and gas tanks on cars are of good capacity. When necessary, gasoline can be carried in the sealed

five-gallon tins obtainable at larger substations and distributing centers. It is advisable to carry an extra quart or two of oil in each car, as the oil consumption of an engine increases appreciably in hot climates and on long tours. In hot weather the grade of oil used should be slightly heavier than that normally recommended for the car. Oil should be checked every hundred miles in cars more than two years old or in those which have traveled more than 20,000 miles.

In loading a car, place the heaviest articles behind the front seat and as near the center of the frame as possible. Avoid overloading the rear end and the running boards. Light bulky things such as tents and bedding may be enclosed in canvas or waterproof cloth and roped on the top of the car. A small locked box may be placed at the rear or on one of the running boards to hold an emergency field equipment of collecting tools. This avoids the trouble of unpacking the load when one is examining exposures along the road.

If the car is to be left in the open during inclement weather, a canvas top cover will serve to protect it. For convenience, the cover should have ropes at its four corners to tie to the front and rear bumpers. The cover will also find use as an awning or to shelter food supplies or specimens. The windshield of the car should be protected during severe sandstorms, lest it become badly frosted.

Difficulties encountered in cross-country driving are dry sand, mud, high centers, and quicksand. With oversized tires, a light load, and slow driving, a car will usually pull through anything except quicksand and dune sand. Avoid the temptation to increase speed when approaching a sand patch. Keep up a steady pull in low gear. If the car sticks, stop the engine immediately to prevent the wheels from sinking, and then shovel away the loose sand from about the wheels and lay down brush, stones, chicken wire, or canvas where the wheels are to go. Try to ease the car very gently forward or backward, again without spinning the wheels. If the wheels have spun down into dry sand, quicksand, or mud,

it may be necessary to place the jack under the hub or axle, raise the car as far as possible, put rocks, brushwood, or sod under the wheels and repeat the process until all wheels are free. Then lay brush and cobbles, sod, chicken wire, or canvas for as long a distance as is necessary to get the car safely across the soft area. If this is unsuccessful a team of horses or a crew of men will have to be obtained.

A car buried in quicksand can sometimes be pulled out by means of a steel cable and a power winch. The engine must then be taken to pieces and given a thorough cleaning; also the axles, clutch, and differential gears. Dry stream beds (arroyos or washes) in arid regions are particularly dangerous when even a small amount of water is running in them. If a car sticks in quicksand under running water more than two feet deep, the chances are that it will be carried completely under in a short time. Never park a car in a dry wash, as local storms can make roaring torrents of these innocent-looking places in a few minutes.

In America, fossil equipment rarely needs to be transported by wagon, pack train, boat, or native porters, although it was formerly common to explore on horseback and carry equipment on pack trains and wagons. Some of the old collectors say that the motorcar has destroyed the romance of fossil hunting, but they probably forget the long hours of horse hunting on frosty mornings and the delays and damage caused by fractious mules, scattered packs, and broken-down wagons, to say nothing of the time consumed in slow travel. Already one may use the airplane for locating favorable collecting grounds, and soon, in rough country, we shall land field parties and equipment with light autogiros.

Equipment necessary for the mule, horse, ox, and camel caravans of other lands is described in such travel manuals as Brouwer's (1925). Native porters are still employed in southern China, India, Madagascar, and East Africa; camel trains in Central Asia, North Africa, and the Levant; llamas and donkeys in the Andes; ox teams in southern Brazil, Rhodesia,

and the Kalahari; canoes and boats in Canada, Central Africa, and the Amazon; pack mules and horses in the mountains of North America and northern China; and the automobile along main routes nearly everywhere in North and South America, Africa, and Australia, because of the rapid spread of road building in these countries.

Besides the particulars of the collecting equipment, to be discussed later, it may be useful to refer to lists of supplies for general use. These may be divided into: (1) general outfit, (2) photographic outfit, (3) cooking outfit, and (4) groceries. For similar lists, including medical kit and personal luggage, see Grinnell (1917).

General outfit.—Tent (with fly and mosquito net in certain regions); large tarpaulin (heavy canvas or light waterproof cloth); folding table, or lumber to make a table; folding stools or chairs; hatchet and axe (with extra handle for each); hand saw; candles; flashlight (1 for each car); battery lamp; gasoline lantern (with at least one dozen extra mantles and cleaning tools); first-aid kit; knapsacks or rucksacks (1 for each collector); 2-quart canteens (1 for each man); 100 to 200 feet of ⅜-inch rope; notebook (1 for each man); notebook paper; fountain pens; pencils; ink (in leakproof container); pocket-size field notebooks; hand lens; forceps; assorted nails; hammer; maps; stationery; postal cards; stamps; telegraph forms. Also plane table, alidade, and Brunton compass, if mapping is to be done.

Photographic outfit.—Camera (according to preference: a good 4×5 or postcard-size camera is the average selection; some use can be made of a smaller camera, also; and a 5×7 camera with cut-film adapters may be included for photographing specimens in place); tripod (with tilting top); roll films. Developing equipment should be taken for work in warm humid regions. In the tropics films should be packed in moistureproof containers and developed as soon as possible.

Cooking outfit.—Flat iron bands such as spring leaves are useful for spreading across a trench, or a piece of sheet metal

may be used for the top of a rock stove. If it is not possible to get firewood, a gasoline stove should be taken. Dutch oven (1 for four persons); frying pans, stewpans with covers; dishpans; pie tins; coffee pot; galvanized and graniteware pails; cups, plates; soup bowls; knives, forks, and spoons; tablespoons; cooking spoons and long fork; pancake turner; can openers; wash basins; and canvas waterbag. Use steel wool or woven copper for cleaning kettles.

Groceries (calculated for one man, one month).—Canned peaches, tomatoes, corn, beans, and jam (total of 10 quart cans); flour (6–8 lb.); breakfast foods (4 lb.); macaroni (1 lb.); rice (2 lb.); beans (3 lb.); potatoes (8 lb.); onions (2 lb.); coffee (2 lb.); cocoa (1 lb.); sugar (8 lb.); bacon (3 lb.); ham (3 lb.); canned or dried meat (8 lb.); canned soup or soup powder (4 pts.); dried fruits and raisins (8 lb.); bread, cookies, hardtack, crackers (total of 10 lb.); eggs (4 doz. if available); canned milk (8 qts.); lard or other shortening (1½ lb.); butter (3 lb.); syrup (1 qt.); salt (½-lb.); cornstarch (3 oz.); vinegar (3 oz.); salad oil (1 pt.); baking powder (¼-lb.); baking soda (3 oz.); pepper (1 oz.); ketchup (½-pt.); kitchen soap (2 bars); matches (1 doz. small boxes packed in tins). To this list may be added various dehydrated fruits and vegetables, milk powder, egg powder, and canned butter, if desired. Staple groceries may be carried in cloth bags.

A good item for a permanent camp is sour dough. To start this, mix a little flour, sugar, yeast, and warm potato water together and after two hours empty this leaven into a granite or earthenware vessel containing a batter of flour and water. Let the mixture set over night in a warm place. Next morning the batter should be very light and frothy with fine bubbles. Allow about a pint of this for each person and throw into it a pinch of baking soda (for each pint of batter), a little salt, and an egg or two, or egg powder. For pancakes, cook on a well-heated and greased griddle or frying pan. For bread or biscuits, mix in more flour and allow the dough to rise

before baking. Keep a cupful of the original sour dough, or even a few scrapings, to start the next batch, and so *ad infinitum*.

To cook beans at high altitudes use a "pressure cooker" with a sealed lid; or boil the beans with salt and pork, and then place them in a large friction-top tin with a few small holes in the lid to let out the steam. Put bacon or chunks of salt pork on the bottom of the can and on top of the beans. Dig a hole two feet deep and build a fire in it, or throw live coals into it. Set the can on the coals, shovel hot coals and ashes around the tin, and cover all with earth. Leave over night or even longer. A little molasses in this won't do any harm. Meat and vegetables can also be cooked this way. Arizona sheepherders take a sheep's head with the wool still attached and bury it in a pit with live coals, to cook the brains and tongue.

In foreign countries it is nearly always possible, less expensive, and more convenient to live on the native products and cookery. This applies to parts of Mexico, South America, Russia, India, East Africa, and China. Many travelers, however, carry their own supplies in these regions, which greatly increases the cost of transportation.

CHARLES L. CAMP

Museum of Paleontology,
University of California,
April 28, 1937.

PART ONE: VERTEBRATES

BY CHARLES L. CAMP

FIELD METHODS

Prospecting for Fossils

Wholly new and extensive vertebrate fossil fields are rarely discovered, so the collector usually contents himself with a careful investigation of some previously known area. With reasonable luck and effort, he may hope to turn up new and better specimens or even a "quarry" that has been overlooked.

Many of the famous fossil beds of North America are in the badland regions of the West (figs. 1, 2). Here fragmentary

Fig. 1. Badlands in the Chinle Triassic, Blue Forest, six miles south of Adamana, Arizona. Phytosaur and stegocephalian horizon (*Machaeroprosopus adamanensis* zone), just below summit of highest hill.

bones lie on the bare, weathered outcrops and guide the fossil hunter to more nearly perfect material. In such localities, fossils are usually distinguishable from the bones of recent animals by their heavier weight, darker or more mottled coloration, and by the way they crack apart in weathering. A petrified fossil usually breaks like a rock, along cleavage

Fig. 2. Skull and jaws of phytosaur (*Machaeroprosopus gregorii*) in Chinle Triassic near Round Rock, Arizona. The skull, partly encrusted with matrix, is on a pedestal and nearly ready for its plaster bandages.

planes at right angles to the grain of the bone. Such a fossil eventually breaks up into small blocks; a recent bone, into elongate splinters and flakes. A practical test is to touch the specimen to the tongue. Recent bone is "greasy," petrified material tends to stick to the tongue. Another test is to apply a lighted match; the organic content of recent bone gives off a distinctive odor. Some fossils buried for millions of years still retain, however, some organic material.

A favorable place to search for specimens cannot always be discovered without some preliminary scouting and testing of the various types of rocks exposed in the region. Sometimes the more homogeneous deposits will appear to be barren, whereas neighboring exposures, showing cross-bedded sandstones or sandstone and shale layers alternating, will seem more encouraging. Alternation of sand and shale together with cross-bedding may indicate rapid filling, as in a delta. Homogeneous deposition may indicate slow accumulation, as in a swamp or lake bed. Sometimes a rock stratum of distinctive color, interbedded with other clays of the same texture but of different color, will contain most of the fossils in the area. Calcareous or nodular layers should always be carefully examined; also light-colored layers in darker rocks. Lenses or layers blackened by carbonaceous or bituminous material are sometimes productive, but the specimens in this dark matrix may be difficult to see.

The usual places for immediate search are on newly eroded slopes where soil does not accumulate and where the rocks are wearing rapidly away. In these areas—badland "breaks," sea cliffs, and riverbanks—the fragile remains may not have had time to disintegrate at the surface of the ground. One should walk or crawl slowly around the bases of such exposures, keeping eyes and mind attentively focused upon every unusual bit of rock, petrified wood, nodule, or other indication of the "level" in which fossils may lie.

Fossil hunting is a tricky business and requires patience, concentration, and powers of observation. A successful pros-

pector may spend all day on a small patch of ground while his companion walks miles over the exposures and finds nothing. The deliberate collector will be searching for clues showing the method of deposition and weathering of the rocks. He may also see minute fragments of weathered fossils that will lead him to the resting place of a specimen.

Examination of unprepossessing nodules will sometimes be rewarded by discovery of material completely enclosed within. If it is necessary to crack these open, try to avoid more than one clean break across the middle of the nodule. In the South African Karoo, most of the surface material is preserved in hard limestone concretions. As there are thousands of these in some localities, the collector must train his eye to recognize the outlines of skulls and bones encased within the stone. Every suspicious-looking lump of rock is scrutinized and the more promising ones are picked up and turned over close to the eyes, for just the point of a tooth or a minute fragment of a bone on the surface may indicate something within.

If a specimen collected as float shows fresh surfaces, indicating that it has been broken recently, make an effort to find the missing pieces and fit them roughly together to see if anything is still lacking. Literally, leave no stone unturned until all possible fragments are collected or until the missing part is found in the rock. It may be necessary to shovel away talus, sweep up the débris, screen it and even wash the screenings, in order to recover the minute fragments. Specimens can, if necessary, be put together from minute pieces, if these are all present and if the edges have not been completely weathered away.

Upon noticing fragments of bone, shells, petrified wood, or other "float," one should make an attempt to trace the "lead" up to the point where such material may be resting in place in the rock. Often this involves some digging with shovel, prospector's pick, or small scratcher, depending upon the size and character of the specimen.

While on reconnaissance, when proper tools are not available, do not attempt to dig out the specimen. Cover it with newspapers and soil, place markers or monuments at the locality, and await opportunity to work it out with suitable tools and plenty of time. Many fine specimens have been ruined by hasty collecting.

Fossils may lie in the earth for millions of years. When the rocks finally wear away, exposing the specimen, it may be only a matter of a few weeks until little or nothing remains. *Every specimen* can be saved in the condition in which it occurs—if care enough is given to saving it. Naturally, the collector must decide whether the effort will be repaid by the value of the fossil.

There are a few kinds of fossils which can safely be collected with only the most meager experience and equipment—such things as hard pieces of petrified wood, lumps of rock containing bones and shells, and well-indurated bone and teeth if found as "float" on the surface of the ground. These are usually of value only if their exact occurrence or stratigraphic level is recorded, for they may then serve to indicate the geologic age and history of the rocks. Much of the weathered fossil material lying about is of no use for scientific study, except as it may provide clues to the collection of better specimens buried near by. Hence, the gathering up of surface fragments by curio hunters may destroy the "leads" to valuable material. Casual visitors at fossil localities should be watched to see that they do not carry away specimens or trample on them.

Excavating

If the specimen proves to be of value, all surface float should be gathered and wrapped tightly in newspapers. Friable fragments should be shellacked. Often it becomes necessary to screen or sift the talus to obtain even the smallest fragments. The work of excavating should begin, if possible, *above* the specimen and not at the side. One may often be tempted to bite into the edge of the bank, but a much cleaner job can be

done on a horizontal surface. The material is uncovered and all parts gently cleaned with scratchers and whisk brooms or soft brushes. Shellacking is done as the work progresses.

Excavating is often the most difficult and exacting part of fossil collecting. Its success depends partly upon proper tools and equipment and partly upon the patience, skill, and experience of the excavator (figs. 2, 21–22).

Tools and Equipment

Where much overburden must be removed, recourse is often had to team and plow, and "Fresno" or slip scraper. The "Fresnos" are made to handle from ⅛ cubic yard to 2 or

Fig. 3. Team and "Fresno" scraper in the *Typothorax* quarry at Ghost Ranch, New Mexico, Chinle Triassic.

even 4 cubic yards at a load. The latter require powerful traction. A ¼-yard "Fresno" can be drawn in loose gravel by two horses (figs. 3, 20). In some districts a small caterpillar tractor with scarifier, and bulldozer or land-leveler, has been used to advantage, but this equipment is expensive to move and is practicable only in large accessible quarries.

Before a team and scraper are brought in, it is imperative to sink prospect holes with pick and shovel to determine the

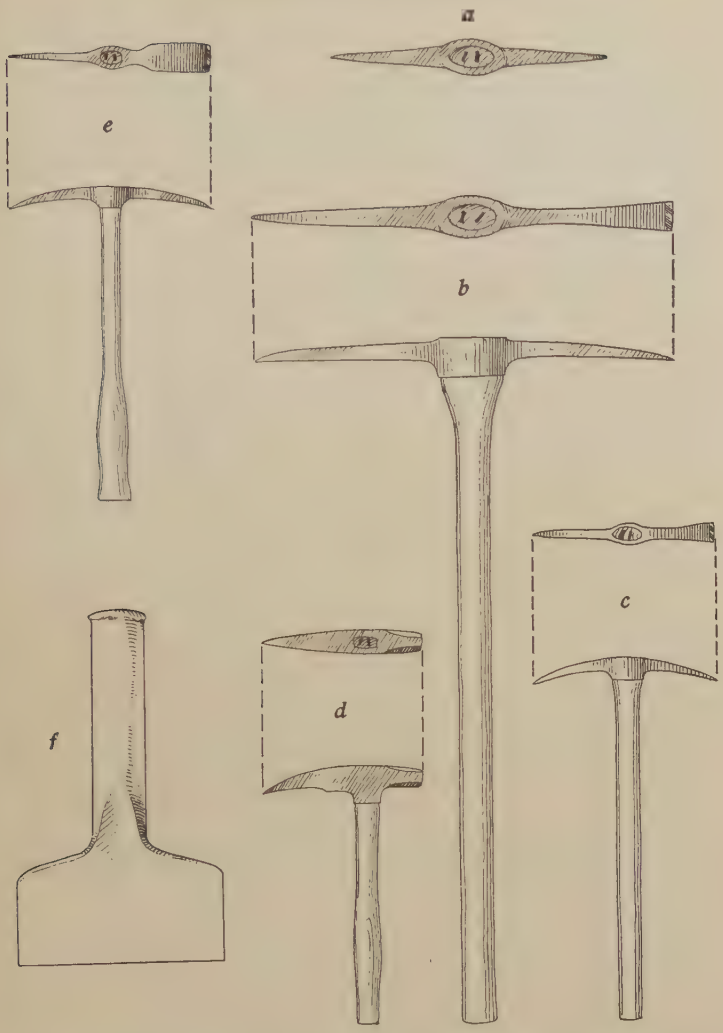


Fig. 4. Types of picks: *a*, "drift" pick; *b*, railroad pick; *c*, "Marsh" pick; *d*, geological "hammer"; *e*, infantry trench pick; *f*, paleobotanical chisel.

exact situation of bone levels. If more than six inches of overburden remain over a large area, the effort of shoveling by hand becomes very great. If much less than this amount is left, there will be danger of damaging the fossils with the scraper. A two-horse team and "Fresno" with driver should

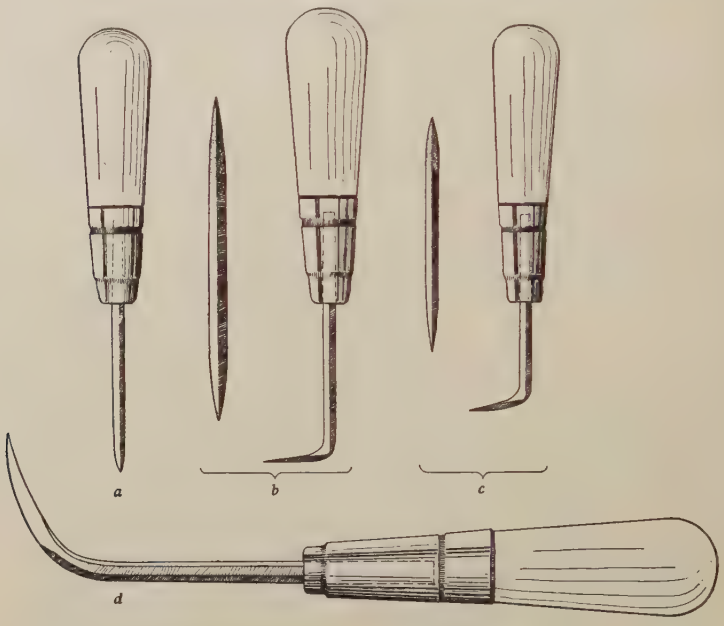


Fig. 5. Awls and scratchers: *a*, small straight awl; *b*, medium scratcher (from large straight awl); *c*, small scratcher (from small straight awl); *d*, large scratcher. × ⅓.

handle 100 cubic yards of soft earth or shale in one day at a cost which in the United States should not exceed $10. A slip scraper can be run with one horse and is more easily transported, but of course it is slower and more expensive on a large job. An automobile can be used to operate a small slip scraper, with a rig of ropes and pulleys. In China, India, and Africa it is cheaper to employ native laborers with their carrying baskets than to buy mechanical equipment.

In quarries covered by layers of hard rock, it may be necessary to blast with dynamite. Such a project should be started from the edge of an outcrop—"shooting" the rock mass out at one side. If one attempts to burrow down into the middle of such a mass, great damage to underlying bone layers may result. The locality of a blast should not be visited right after the explosion, as the gas is nauseating. It will pay to get an expert to handle the explosives, for the fuse caps are dangerous.

Fig. 6
Chinese pick.
× ⅓.

Tools for excavating include: shovels, large railroad picks, small "drift" picks, paleontological or "Marsh" picks (fig. 4*c*), which, by the way, are more expensive and scarcely better than a good, light "drift" pick (fig. 4*a*). A crowbar is sometimes handy. The smaller tools often used are: infantry-style trench picks, prospector's picks or geological "hammers" (fig. 4*d*), large and small curved scratchers or scrapers, straight awls (fig. 5*a–d*), whisk brooms, large paintbrushes (these are softer and better than whisk brooms for delicate work), trowels or flat coffee cans for rapid removal of loose dirt, and pocket knives.

The Chinese pick (fig. 6), used by the coolies in Szechuan, is a useful tool. It is fitted at the lower end with a removable steel point and the upper end is protected by a double ring of rawhide twisted on when wet so that it shrinks tight when dry. The pick is held against the rock and struck with a 2-pound iron hammer. If several of these picks are used at once, large blocks of matrix can be split away. The tool is also handy when one is turning over blocks containing specimens.

Shellac should be "pure white," not orange nor compound. It must be thinned (½ to ⅔) with alcohol. Fresh shellac

requires a dilution of half-and-half and should never be so thick as to form a gummy coating on the specimen. A shellac pot can be made of an old fruit jar or mayonnaise jar by punching a hole in the lid and wrapping string around the handle of the round shellac brush to close the aperture when the brush is not in use (fig. 7). In this way the brush remains moist and free from dirt.

Fig. 7
Shellac bottle and brush.

Bear in mind, when preparing specimens for removal, that an extra hour or two in the quarry may save several weeks' work in the laboratory. For this reason, "jacket" all fragile and valuable material wherever possible. Photograph, draw, and record carefully the positions of all blocks in the quarry, and draw up a plat and numbering system to be recorded handily in a notebook. The plat of the quarry may be divided into squares of convenient size and laid out by means of stakes, stakes and string, or overhead wires. When, in cave excavations, depth records have to be kept, they can be painted on the rock walls. Plane-table surveys to record exact boundaries, contours, and so forth, must occasionally be made. Consult Lahee (1923) for instructions on mapping.

Method of Jacketing Specimens

In preparing a specimen for jacketing, excavate all around it, exposing just as little as possible of the actual surface of the bone. Let the specimen remain on a pedestal with overhanging edges (fig. 8) to hold the plaster cap. Use shellac liberally when the specimen is *dry;* moist bone will not receive the shellac. When the shellac is dry, cover the specimen with a sheet or with strips of wet newspaper to prevent the plaster from coating the bone (fig. 9). Start jacketing. Provide a quantity of old burlap such as potato or oat sacks of coarse

weave. Most of these sacks are sewn with an old-fashioned chain stitch which will easily pull out when properly started. Lay out the unraveled sacks and slice them into strips 2 to 6 inches wide and 1 to 3 feet long. Put these strips in a pail of water to soak. Now provide a washpan or dishpan half full of water and sprinkle plaster of Paris slowly into it until the

Fig. 8. Preparing a block for jacketing. Abo Permian near Coyote, New Mexico.

plaster just begins to rise above the surface of the water. Allow the plaster to settle gently without much stirring. Wring out a burlap strip, dip it into the plaster, remove the excess, and cover the surface of your specimen with this and with other strips (figs. 10 and 13). When the specimen is covered, wind a "collar" about the base of the entire block, using a long strip of burlap and pulling it tight. Then, when the blocks are turned over, they will not fall out of their plaster caps. Large blocks may be reinforced with sticks and wire (fig. 11).

When the top jacket or "cap" is set and allowed to dry,

preferably for 24 hours, excavate well below the level of the cap all around the pedestal and finally under it. Then quickly and gently turn the specimen over and remove the excess rock from the under side. Bring this phase of preparation down to within an inch or so of the bone on the lower side

Fig. 9. The same block; laying on strips of wet paper to prevent plaster bandages from adhering to the specimen.

of the block. Soak this side with shellac, and finally complete the block with bandages and plaster firmly around the under side.

Plaster of Paris may be purchased in several grades—dental, flasking, casting, and gauging. Gauging plaster is made up in "slow-set" and "rapid-set" varieties. The "slow-set" requires an hour or longer to become firm. It sets hard even after much stirring and manipulation and is superior to the "rapid-set" for all purposes except when it becomes necessary to take out a block immediately.

Flour paste may be used when plaster of Paris is not at hand. This sets well in warm weather but cannot be used in

frosty seasons or in rain. It tends to mold if not thoroughly dried or treated with corrosive sublimate, and it is subject to attack by rats and mice. Moreover, it will not form as firm a jacket as plaster.

Gypsum may be burned in an oven at a temperature of about 250° to make plaster of Paris. Ordinarily it does not

Fig. 10

Fig. 11

Fig. 10. Bandaging a block with strips of wet burlap soaked in plaster. Abo Permian. Fig. 11. Block bandaged on one side and reinforced with sticks and wire.

pay to do this in the field, for in this country the plaster may be purchased for 1½ cents a pound. For lack of other material, Portland cement may be used; but jackets made of this are difficult to remove in the laboratory.

Smaller blocks can be made with less trouble and expense than larger ones, in the manner now to be described.

When bones lie in masses,—entire skeletons, plaques of skin plates, and so on,—it may be possible to excavate and wrap the blocks so that they may be broken or hack-sawed apart. (This cannot be done safely if large skulls are contained in the blocks.) What would normally be a large, unwieldly block weighing 1000 pounds or more may be separated into

Fig. 12. View of quarry on Ramon Salazar ranch.
Abo Permian, near Coyote, New Mexico.

four blocks of less than 200 pounds each by "collaring" the breaks and pulling the blocks apart after tunneling under the middle of the specimen (see fig. 14*a–f*).

After the pedestals and tunnels are completed (fig. 15), bandages are wrapped around the blocks in the normal way except that "collars" are bound tightly, parallel to the breaking point between the specimens. Collars are brought through the tunnel and are reinforced with baling wire, twisted tightly in order to hold the open ends of the blocks. These are the vertical collars. Horizontal collars and wire are then brought around the necks of the pedestals. The plaster is allowed to dry and the blocks are ready to be pulled apart.

One block is held steady while the other is lifted gently and swung from side to side, finally being pulled away and turned. The bones at the break usually part neatly and seldom drop any fragments. In this manner, smaller blocks may sometimes

Fig. 13. Small blocks being prepared for removal from floor of quarry. "Collar" is being wrapped around block in center. To the right an excavator is preparing a block for bandaging. To the left a bandage is being removed from the basin of fresh plaster. Same quarry as shown in figure 12.

be broken away from a larger specimen without damage. It is always better, however, to get out a skeleton in one block if it can be done.

In sandy matrix a long wire may be used as a saw to undermine large pedestals. Sticks or splints may be used to advantage in keeping jacketed specimens braced. On large blocks, poles may be bound into the sides of the block, used as handles, and then nailed to the sides of the crate when the specimen is shipped. Jacketed specimens may be laid on straw, hay, or leaves in sacks and transported to the railroad, or to a place where lumber can be obtained.

Float and fragmentary specimens are wrapped in news-

papers and securely tied in small packages with labels inside and out. These labels should ordinarily include a locality number and the field number of the collector.

In handling delicate, crumbling material, special precau-

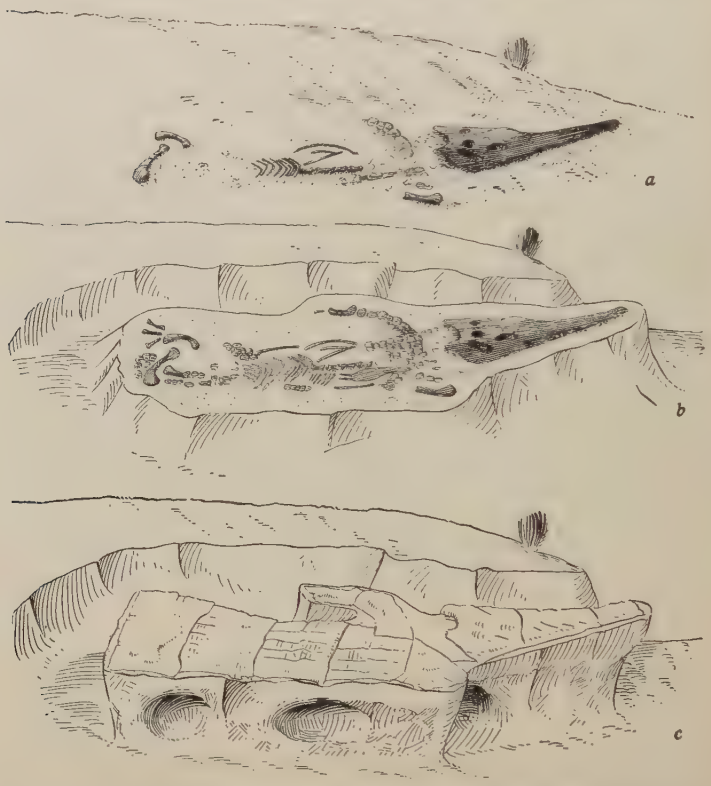


Fig. 14. Steps in excavating and jacketing: *a*, specimen before excavation; *b*, specimen excavated and raised on pedestal; *c*, pedestal cut close and tunneled, and wet papers applied to specimen.

tions must be taken. If the surface of the specimen shows any tendency to flake off, it may be wise to spray it with gum-arabic water or very thin liquid celluloid instead of shellac. Then lay on strips of tissue paper or Japanese rice paper, wetting these through and through with gum water and

allowing the whole to dry before jacketing. The gum water is made by dissolving lumps of commercial gum arabic, or the clear gum which exudes from the acacia (mimosa) tree, in an equal quantity of water. Gum is much more easily re-

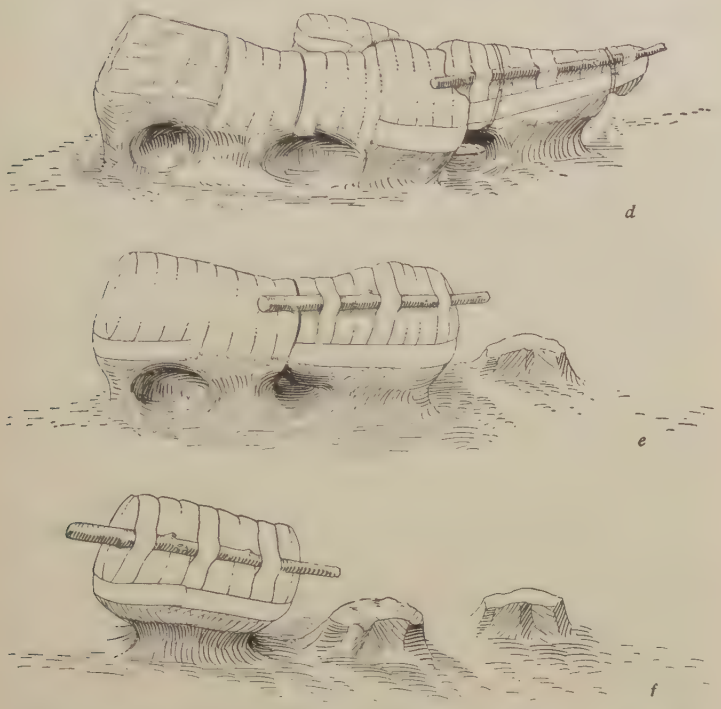


Fig. 14. Steps in excavating and jacketing (*continued*): *d*, jacket supported by strips and wire; *e*, after removal of first block; *f*, after removal of second block.

moved in the laboratory than shellac, and it holds the tissue paper equally well in dry weather.

A shellac substitute recommended by Frentzen (1932) is the preparation known as "Durol." Another compound called "Demovit" can be used for removing the moisture from a specimen before "Durol" is applied. These preparations are

Fig. 15. Preparing to bandage a large block. Specimen is on a pedestal and the tunnels are completed. This specimen may be removed in one piece. Chinle Triassic, Ghost Ranch, north of Abiquiu, New Mexico.

obtainable from the Menzer Chemique Fabrik at Karlsruhe-am-Rhein, Germany.

Gum arabic and shellac cannot be used on wet specimens. If the material cannot be dried out, it may be thickly coated with beeswax and then removed in the wax lump; or jacketed. Special solvents such as benzene may be employed in the laboratory, to remove the wax. In this way, Mr. Hugo Goeriz excavated the skull of a fossil rhinoceros found below high-tide level on the shores of San Francisco Bay.

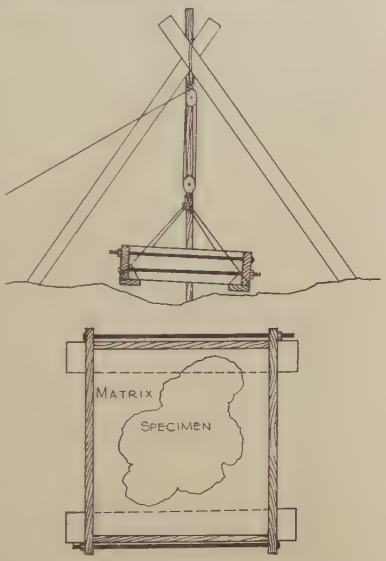


Fig. 16. Use of tripod for large box with bolted frame.

Near Halle, in Germany's Geiseltal, is a remarkable deposit of Eocene brown-coal or peat containing plant and animal remains in abundance, embedded in a soggy matrix. The fossils are of the utmost delicacy, showing the original colors of beetle elytra, the internal organs of insect larvae, the hairs and sweat glands of Eocene mammals, the skin of frogs with preservation of the cell structure including the chromosomes, and the cell structures of leaves and pollen grains. The vertebrate remains include lizards and bats with preservation of skin, muscle, and bone. In order to excavate this material successfully, it was found that the specimens, partly uncovered in the matrix, could be coated with liquid celluloid (cellulose acetate) sprayed on and allowed to dry. The celluloid used is a flexible type supplied by the Agfa Film factory. This will not become brittle with age.

After the celluloid has dried, the whole is embedded in a

Fig. 17. Professor Clive Forster-Cooper and party excavating in the Devonian Old Red Sandstone at Achanarras, near Thurso, Scotland. Specimens of primitive fishes appear on the surfaces of the large slabs.

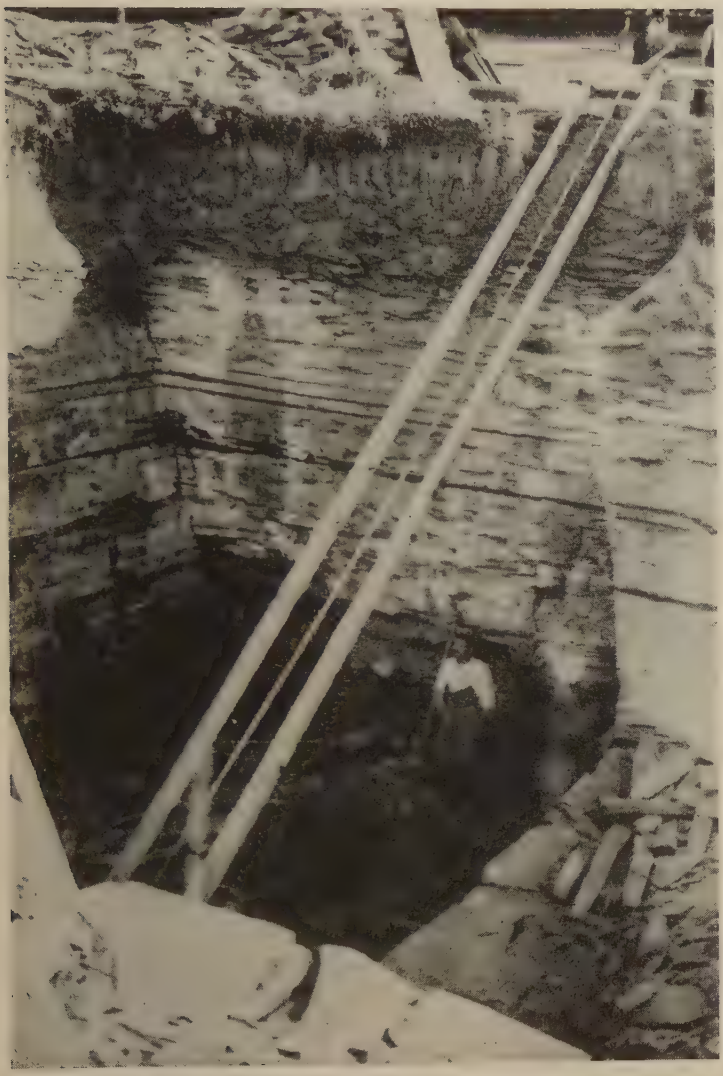


Fig. 18. One of the commercial slate quarries at Holzmaden, Lower Jurassic of Württemberg. Fine examples of sea reptiles, fishes, and crinoids have been recovered from these quarries by Mr. Bernhard Hauff.

block of paraffin and this in turn may be covered with a plaster jacket. The specimen is then removed to the laboratory, where it is worked out from the under side. It is allowed to remain fastened to its celluloid frame as a permanent preparation. The microscopic specimens are obtained by macerating the material with ammonia, after which the specimens

Fig. 19. Transporting a large block lashed to a pole. Abo Permian, one mile south of Cañon d'Agua, New Mexico.

are picked out and mounted in balsam on a microscope slide. For further information see Voight (1933, 1936), Walther and Weigelt (1931), and Weigelt (1931). A further note on the use of paraffin in handling fossils is given by G. A. Cooper (1933).

For collecting exceedingly large slabs or blocks, it may be desirable to crate the specimens *in situ,* using heavy lumber and long iron bolts. The sides of the crate may be bolted around the specimen on its pedestal and a tripod built up over the box and equipped with block and tackle or chains to raise and turn the specimen (fig. 16).

In quarrying material from extremely hard rock, an ex-

pensive procedure, it may be possible to work up to the material on one side, leaving a free edge down to the first bedding plane below the bone (figs. 17, 18). The bone blocks may then be freed by drilling a series of small holes with sledge and miner's drill. The block may then be split away by "plug and feathering" as in quarry work. The "feathers" are two half-

Fig. 20. *Placerias* quarry. Chinle Triassic near St. Johns, Arizona. The excavation was divided into squares 20 feet in diameter and the location of each specimen was recorded.

cylinders of wrought iron which just fit the tip of a tapering steel "plug," usually about the size of a railroad spike. The "feathers" are inserted into the holes and the "plug" is driven between them, wedging or splitting off the block along the line of holes. It is best to provide plugs and feathers for all the holes and to strike each lightly with the sledge—pounding in the plugs evenly all along the line to insure a clean break.

The blocks of stone, if hard enough, may be shipped in crates; but it will usually be preferable to build boxes to fit the block and to pour plaster all around, protecting the bone surface with newspapers to prevent the plaster from sticking to the bone. Handling heavy blocks in rough country can

be done by horse-drawn "stone-carts," or by the sleds called "stone-boats," also horse-drawn, or by lashing the block to a carrying pole (fig. 19).

Numbering Specimens

Our practice has been to use collector's numbers in the field and to assign museum numbers to specimens only after their receipt at the museum. A collector's locality numbers start at 1 and are carried consecutively through the years. His specimen numbers begin at 1 in each locality. Locality 70, specimen number 3, would be $\frac{70}{3}$. If several packages of specimen 3 are made up, these might be labeled $\frac{70}{3\text{–}1}$, $\frac{70}{3\text{–}2}$, $\frac{70}{3\text{–}3}$, and so forth. Ordinarily, a locality includes specimens from a single geologic horizon in an area easily delimited upon a map or sketch included in the field notes. Numbers may be written on a slip of paper enclosed with the original package in the field. After preparation in the laboratory, the museum number is written on the surface of a spot of white "Duco" or lacquer applied to the specimen.

The careful collector saves all fragments of his specimen as well as every scrap of information concerning its occurrence. This information includes: (1) the exact map locality, Range, Township, and Section data being used where available; (2) for future reference, a description of the immediate locality, often accompanied by photographs or sketches; (3) a record of the geologic features: formation, exact level or horizon, associated plant or animal remains, structure of the deposit, and the nature of the matrix; and (4) records of the position in which the specimen was found, accompanied by photographs and sketches where desirable.

Persons in charge of the work of excavation should pay close attention to the nature of the matrix in which the bones occur, as well as to the condition of the bones themselves. Specimens of the matrix may be collected for analysis, and

the presence of organic material such as coal, charcoal, and plant stems or impressions should be recorded, as these may give clues to the local environment and climate. The occurrence of ripple marks, gypsum layers, mud cracks, waterworn pebbles, cross-bedding and other features of the matrix may be noted. The size and character of the grains of sand or silt,

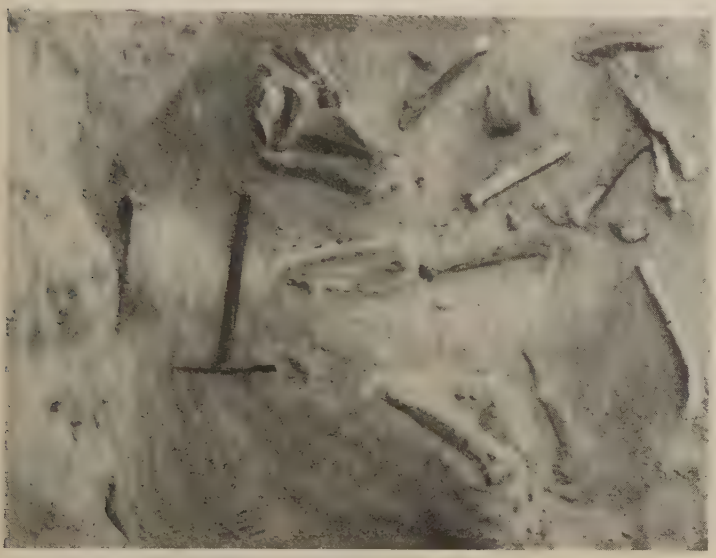


Fig. 21. Skeleton of primitive camel, *Procamelus*, in sandy matrix. Big Spring Canyon, Lower Pliocene, near Martin, South Dakota.

thickness of the bedding, attitude of the beds, and position of the fossil zone in the beds with reference to some easily distinguishable rock layer or unconformity in the region—all may be important. The fossil is a part of the sedimentary history of the rock and may give indispensable geologic and stratigraphic information. Twenhofel's treatise on sedimentation (1926) is a useful reference.

Another phase of collecting is the study of the nature of the fossils: the degree of petrification, the degree of sorting or scattering of the remains, the possibility of associating

and piecing together broken or scattered material, the possible presence of waterworn or partly rotted material, and the position of the specimens in the matrix as an indication of the manner of their burial.

An item often slighted is the obtaining of authorization or permission for excavation and exploration from the owners

Fig. 22. Skeleton of North American horse, *Pliohippus*, in solidified sand. Hemphill quarry, Middle Pliocene, near Miami, Texas.

of the land; or from the county, state, or federal government. The Department of Agriculture and the Department of the Interior require permits for all work on government land. Several states have laws forbidding excavation of "antiquities" within their boundaries without permit.

Cultivate the acquaintance of local people who may know of the occurrence of fossil remains; storekeepers, sheepmen, cowboys, hunters and trappers, prospectors, and road crews often have information of value in a new country. Buy supplies, if possible, at the local store; the cost may be slightly greater, but one gets dividends in information and goodwill.

Shipping Specimens

Small material wrapped in newspapers may sometimes be shipped (by express or freight) in light wooden soap- or baking powder boxes. It is ordinarily better to purchase clear lumber and construct boxes. Specifications, in inches, for a box of convenient size, are as follows (fig. 23) : top and bottom pieces, two that are $1 \times 6 \times 36$ and two that are $1 \times 12 \times 36$;

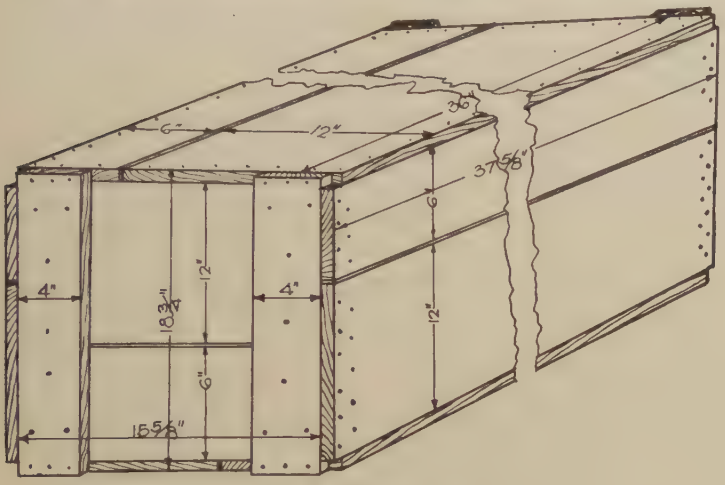


Fig. 23. Shipping box.

sides, two that are $1 \times 6 \times 37\frac{5}{8}$ and two that are $1 \times 12 \times 37\frac{5}{8}$; ends, two that are $1 \times 6 \times 15\frac{5}{8}$ and two that are $1 \times 1 \times 15\frac{5}{8}$; and four uprights, $1 \times 4 \times 18\frac{3}{4}$ inches.

Wrapped specimens, properly labeled, are packed tightly so that they will not settle and shake about during shipment. Heavy specimens should not accompany fragile material in the same box unless protected by a partition nailed securely across the inside. Plaster blocks should be packed firmly in excelsior, which can sometimes be purchased in bales. Failing this, hay, straw, wool, rags, old sacking, crumpled newspapers, or even leaves and brushwood may be resorted to. Each box should be numbered and its contents noted.

LABORATORY METHODS

Fossil preparation is delicate, tedious work, requiring preparators who are possessed of patience and experience. The best method of training a man is to give him some field experience followed by close supervision in the laboratory. He should not be put to work on fragile material for several months. Relatively few men ever qualify for the more exacting jobs. A good technician develops his own methods, but even the expert finds it necessary to refer to manuals such as those cited below.

The treatises and articles written by Bather (1908), Drevermann (1928*a*), Efremov and Kuzmin (1931), Ehrenberg (1929), Fraas (1910), Prokhorov (1929), Seitz and Gothan (1928), and Stromer (1920) are useful; but Bather's short summary is the only one of these in English. Adam Hermann's account (1909) of the American Museum technique is available to nearly everyone, so we shall not repeat all that he has to say. He emphasizes two important things which we heartily endorse. The first is: A few extra hours or days of careful work in the field may save months of work in the laboratory. The second: A delicate piece of work should never be given to an inexperienced preparator. A short article containing a series of illustrations of steps in the collection and preparation of fossils has recently been written by Simpson (1937); see also Simpson (1934), Hrdlička (1904), Hennig (1932), Schuchert (1895), and Sternberg (1931, 1932).

Tools and Equipment

Laboratory furniture should include large sand tables made by enclosing the top of a strong 3 × 5-foot table in a 1 × 6-inch frame. Smaller rotating sand tables mounted on revolving stools are useful. Mended specimens are laid on the sand until they harden and the sand tables are used to receive large blocks during preparation. As close work and dust are hard on the eyes, the laboratory should be lighted with a

skylight or with daylight lamps, and should be well ventilated. Hand tools for use in preparation include awls, scratchers, chisels, hammers, wooden mallets, scrapers, wire brushes, paintbrushes, knives, mounted needles, whisk brooms, and toothbrushes. Awls and scratchers are made up from the larger "Nichols" 4- to 4¾-inch awls used by harness makers. These awls may be purchased from Bartley & Hall, Inc., 52 Warren Street, New York. They may be sharpened into chisel points and used as small chisels; or they may be mounted in wooden handles and used as straight awls. After heating, curving, and retempering, they are indispensable as scratch awls or "scratchers" (fig. 5) in the field and laboratory.

Fig. 24
Preparator's needles.

Needles mounted in wooden handles, in metal handles, or in wooden handles provided with a metal "chuck," are useful for fine work. Old "Victrola" needles may be used; also tapestry needles. These are not hard enough for some purposes. A better steel for making points is available in the dental "burrs" provided by dental supply houses. Worn-out burrs from a dentist's office are as good as new ones. These are ground down and mounted in handles, and are extremely durable. A needle mounted in a solid brass handle is shown in figure 24*a*; the metal handle is superior to a wooden one when a hammer is being used. A needle ground from the hard steel of a dental burr and mounted in a homemade wooden handle is shown in figure 24*b*.

Bernhard Hauff (1930), at Holzmaden, keeps at hand a supply of homemade scrapers of various shapes for preparing specimens in hard shale. The points in these are of the

best Solingen tool steel. The handles are fitted so that a powerful grip with both hands can be obtained, and the handles are sharpened like pencils when the steel points wear away (fig. 25*a*). Similar tools are used by the Japanese wood and

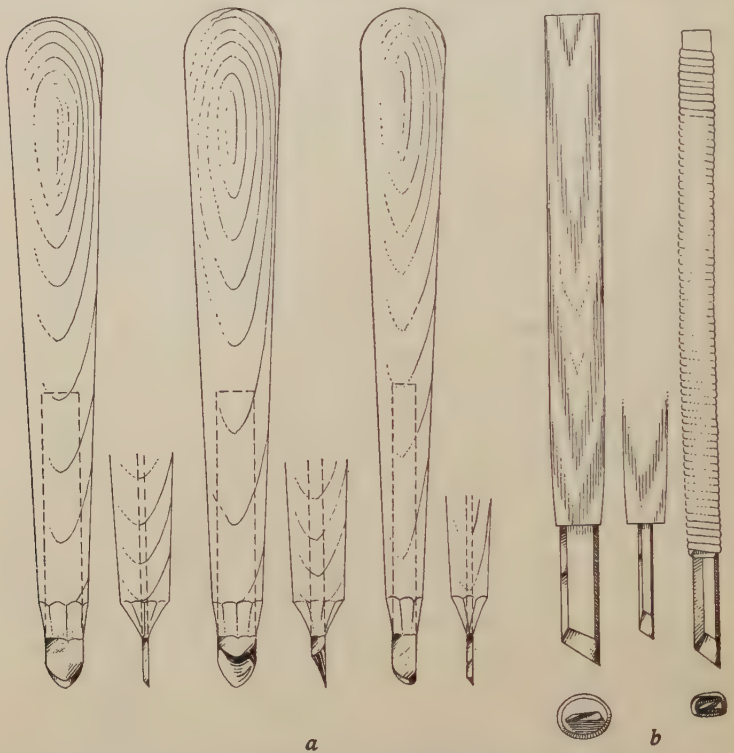


Fig. 25. *a*. Types of scrapers for hand use in hard shale. These are some of the styles made and used by Mr. Bernhard Hauff at Holzmaden. × ½. *b*. Chisels used by wood carvers and seal carvers in Japan. One is wrapped with rattan. × ½.

stone carvers (fig. 25*b*). The steel in these, however, is usually not of supreme quality.

Assorted sizes of small cold chisels, center punches, and other implements are useful. A tool for rapid work in breaking off chunks of matrix at a distance from the specimen can

be made by grinding down the peen or narrow end of a small, metal, machinist's hammer, chasing hammer, or shoemaker's hammer, into a chisel-like shape and using this for striking.

Steel wool, sandpaper, and wire brushes are used in smoothing the surface of the matrix around a specimen on a slab. Wire brushes can sometimes be used directly on a very hard specimen. A "pencil brush" (fig. 26) can be made by enclosing a bundle of No. 10–14 steel piano wire in a rubber or metal tube, taped for the hand-hold, and wrapped at each end with softer wire. The ends of the coil may be unwound as the brush wears down.

Fig. 26 Wire pencil brush. × ½.

The laboratory should also be supplied with electric lamps on stands with extensible arms, a hand lens, forceps, reading glass on stand, binocular microscope on extension arm, carpenter's tools, and machinist's hand drills.

Apparatus in the laboratory should include: (1) a quarter-horsepower, variable-speed, direct-current motor fitted with a standard shaft and chucks to hold an assortment of drills, grinding wheels of various grades and sizes, diamond saw, sharpening and buffing wheels; (2) a small dentist's motor equipped with foot pedal and long flexible shaft for fine tools, an assortment of dentist's tools; (3) gas burner, oven, large glue and papier-mâché pots, and rack for heating and tempering tools; (4) small hand vacuum cleaner; (5) plaster bins; (6) large sink with wire draining trays; (7) chests of drawers for tools; and (8) a large screen sieve.

Chemical reagents, solvents, adhesives, and so forth, kept at hand are: hydrochloric, nitric, sulphuric, and hydrofluoric acids; gasoline, distillate, benzene, amyl acetate as a solvent for a stock can of cellulose-acetate cement, shellac, alcohol, gum-arabic stock solution, water glass, "plasteline," modeler's clay in a rustproof air-

tight pail, lard oil for treating specimens before casting, and a stock of good commercial or prepared glue for making glue molds.

Preparation of Specimens

When specimens from the field come into the laboratory, the first care in opening the packages is to see that the collector's original field numbers are kept with the material to which they pertain. The loose, uncleaned pieces are then placed with these numbers in shallow pasteboard trays of various sizes, which may be arranged in drawers. The material is then ready for cleaning and piecing. This task depends on the nature of the fossil and its matrix. Clays and sands may be easily brushed or washed away, the rough contacting edges are well cleaned with water and a toothbrush, and the pieces, when dry, are stuck together with water-glass cement, cellulose acetate, or plaster. Large pieces may be drilled to receive iron rods or dowels to give strength. If the fragments remain in blocks of matrix, it may be best to piece the blocks before working down to the bone. It is gratifying to see what can be done in piecing small broken fragments when care has been taken in the field to gather up every one of them. For methods of restoring shattered human skulls see Taeger (1930).

Various adhesives can be recommended for piecing together broken fragments, such as may occur in the float below a specimen. Cellulose-acetate cement (celloidin or liquid celluloid) is good for joining clean breaks where there are no open spaces to fill in. It is waterproof and dries quickly and firmly. "Dupont Cement" is the trade name for a clear, white product somewhat preferable to the yellowish "Ambroid." This may be made opaque white by the addition of glycerin. A powerful and excellent cement is made by mixing water glass (sodium disilicate, $Na_2Si_4O_9$) with from 20 to 30 per cent talc to the consistency of cream. This may be colored with ocher or other powdered pigments and can be made a shade darker or lighter than the specimen. An exact imitation of the color of a specimen is not desirable, as in the future

one may wish to know what parts of the specimen have been restored. Water glass is sold as "egg preservative." It does not evaporate rapidly and is not waterproof; but it can be made nearly so with a coating of shellac. Plaster of Paris is used to repair large breaks or gaps in material, to restore missing parts, to remodel skeletons, and to make molds and casts.

The best plaster cement for mending, in our experience, is the gum plaster made with a dilute solution of gum arabic. The gum is purchased in dry lumps and these are allowed to soak in water until a saturated stock solution is obtained. A few drops of corrosive sublimate will check mold. The stock solution is diluted with about three parts of water and used in place of water when one is stirring up the plaster in a rubber bowl. Ocher and other pigments may be added, for the brilliant white of the plaster is not usually pleasing in contrast with the specimen. Gum plaster sets less rapidly than the ordinary mixture and will work nicely under the modeling knife or scraper after it sets.

A favorite adhesive, widely used in the past, is "Keene's Cement," made by mixing plaster and liquid glue. This mass sets harder than gum plaster, is more difficult to trim down, and does not make so neat a job. It is not to be recommended for permanent work, as the glue will deteriorate and specimens mended with it have been known to fall to pieces. The same difficulty has been had with ordinary glue and with photographer's paste. Ordinary glue should never be used, even for temporary work, as it is difficult to remove and will prevent plaster from adhering to the surfaces.

A good technician will study and test the character of his specimen and its matrix before starting to work upon it. The fossil may be a crumbling, fragile thing, requiring special hardening fluids before it can be touched. It may be encased in extremely hard matrix, requiring special tools. It may be susceptible to treatment with acids, possibly a matter for experimentation. It may contain impressions of skin, scales.

cartilage, ligaments, muscles, digestive tract, or stomach contents, all of which might easily be destroyed by a preparator whose attention rested only on the bony skeleton.

Specimens improperly collected, and those which flake or crumble, should be treated with shellac, "Durol," or gum arabic before one attempts to prepare them. Thin skulls or other extremely fragile, porous material may be soaked in "Bakelite" solution and baked in an oven. This will completely harden the most delicate specimens without adding much to their weight or greatly affecting their color. See Hanna's section in this manual for details of the "Bakelite" method; also Case (1925) and Swinton (1933). The fumes from "Bakelite" solvent are irritating and inflammable, and the work must be done in a well-ventilated place.

A method of impregnating with resin is described by Davidson (1933). The dry specimen is dipped into a 3 per cent solution of tartaric acid in acetone. After evaporation of the acetone, a resin is left in the porosities of the bone.

Blocked or bandaged material received in the laboratory is laid on a sand table, and one side of the plaster block is moistened and cut away so as to expose the matrix (fig. 27). The block may, if necessary, be set into a firm plaster cast to prevent shattering during preparation. After the specimen is cleaned on one side, a plaster cap, reinforced with wire or iron rods, is set over it, care being taken to separate the plaster from the newly cleaned and shellacked surfaces by means of damp papers. When the cap has set, the block may be turned over, reëmbedded in plaster, and worked out on the other side.

Specimens in hard matrices, such as iron oxide, calcareous and siliceous nodules, and hard limestone and sandstone, may have to be chipped out carefully with a light hammer and chisel. The greatest care must be taken not to injure or scratch the surface of the bone, and proper use of these tools comes only with experience in handling them. Motor-driven drills and dentist's tools, carborundum wheels, diamond saws,

Fig. 27. Half-prepared block, with plaster bandages remaining on under side. Primitive camel, Big Spring Canyon, Lower Pliocene, South Dakota.

and wire brushes are useful, especially the "Moto-Tool" described below.

Some technicians employ various kinds of portable automatic chisels such as the large pneumatic hammer used by cutters of monumental stone, the automatic center punch, and the dentist's power-driven automatic drill, mallet, or "plugger." A type of the latter developed by F. R. Parrington is sold by the Instrument Supply Company, of Cambridge, England. E. A:son Stensiö employs successfully three styles of motor-driven, automatic, eccentric dental mallets. One of these, the commercial type, is a tool slightly larger than a fountain pen. It is run from a flexible shaft attached to a small, variable-speed, electric motor. The rate of vibration of the needle can be varied by means of the motor rheostat, and the amplitude of the stroke is adjustable on the instrument itself. Also, the needle will cease vibrating when too great an obstruction is encountered. This dental mallet costs about $5. It comes provided with a rubber washer on one of the moving parts. This wears out quickly and can be replaced by a metal washer. The instrument will last about a month under constant service.

The second type, which Stensiö had made to order at a cost of about $50, is similar to the first but about twice as large. The third, an automatic drill which vibrates only when the needle is in contact with the matrix, is a more powerful instrument for harder matrices. Efremov and Kuzmin (1931) advocate a similar "striking, dental, perforating drill" manufactured by Zimmermann in Munich. This operates through a flexible shaft from a two-tenths horsepower, high-speed motor. A similar series of automatic instruments called "dental engine pluggers" are made by Cash, Sons and Co., in London, and were formerly supplied to dental supply houses in America. Dentists seldom use them now, as they tend to destroy the nerves in the tooth pulp, and the old ones have been bought up by manufacturing jewelers for use as chasing and engraving tools. Our experience with some of these instru-

ments has shown that they must be run from a very heavy flexible cable, as they tend to twist a light cable apart in short order.

A tool we have found most useful is a light electric motor which can be held in the hand. It is fitted with a small carborundum wheel. The Dremel Manufacturing Company, of Racine, Wisconsin, manufactures such an instrument, which it calls the "Moto-Tool." The $\frac{3}{32}$-inch chuck for this will fit the shafts of some small carborundum wheels about an inch in diameter and as thin as cardboard. They cost about 3 cents apiece and are excellent for grinding down ironstone and other hard matrices.

The "Moto-Tool" is served by a flexible cord and can be held in any position over a specimen. When working with the grinding wheels, one must guard against touching the wheel to the specimen. It is best to work away the last thin shell of matrix with a hand needle or with the dental mallet.

Rapid accumulation of rock dust obscures the work. This can be eliminated by rigging up a small blower attached to the same motor as the automatic drill and fed into a small rubber tube, the nozzle of which may be attached to the nose of the drill. Accumulation of débris on larger blocks can be avoided by the use of a small hand vacuum cleaner. Rock dust in the air, however, is more dangerous, as it may cause silicosis, a severe respiratory disease, which caused the deaths of several preparators in Amalitsky's laboratory in Russia. In order to avoid siliceous dust when using grinding wheels, we have built a large box with a plate-glass top enclosing a motor-driven shaft on which the grinding wheels are set. Armholes provided with "sleeves" allow manipulation of the specimen inside the box.

Motor-driven grinding wheels may be purchased in many sizes and in a number of materials, carborundum being the most useful. Peyer at Zurich uses a powerful carborundum cutting machine fitted with grinding and cutting wheels about a foot in diameter and run by a large electric motor.

The veteran preparator, Bernhard Hauff, employs huge motor-driven diamond saws to trim blocks of slate from the Holzmaden quarries. These saws may be purchased in many sizes. A small one, 4 to 6 inches in diameter, made of copper, in the edge of which diamond bort is embedded, is useful in cutting away small specimens in hard pieces of matrix.

In spite of these labor- and time-saving devices, the greater part of preparation must be done by slow and tedious hand methods, sometimes under a reading glass or a binocular microscope. Close work on minute specimens requires the smallest needles obtainable. Mount these in wooden handles and sharpen them on a fine-grained oil stone. The surface structure will be much plainer if the specimen is kept moistened with some medium of high refractive index such as oil of aniseed or xylol. Stensiö (1927) discovered this when dissecting ostracoderms, and found it advisable to use refractive media whenever there are sutures or other structures that cannot be distinguished in the dry material, especially where the color and texture of the fossil makes it indistinguishable from the matrix.

Small specimens may be encased in plaster before preparation is started, or they may be cemented with plaster to the rough surface of a brick or stone slab. A small canvas bag filled with sand may also be used to support the specimen.

Acids are sometimes used to clean specimens; also to help differentiate the bone from the matrix during preparation, but this is seldom desirable or even possible, for any acid which attacks the matrix may cause some injury to the specimen. Tests should first be made to determine whether the specimen will be damaged. In general, hydrochloric acid may be applied to specimens in limestone, sandstone, and shale where the grains are united with calcareous cement. Sulphuric acid will remove thin encrustations of iron (haematite or limonite); hydrofluoric is available for unusual occurrences in sandstone with siliceous cement, flint, or chalcedony. Bulman (1931) has made excellent preparations of

the delicate carbonaceous remains of the tadpole-like *Palaeospondylus*, by rotting the dense sandstone matrix with hydrochloric acid. He then cements the specimen to a microscope slide with "Kollolith" (a substitute for balsam) and picks away the loosened sand grains. Final embedding is done in glycerin jelly. Miss Steen (1931) has found it possible to make successful preparations of the refractory Linton amphibians from the coal beds of Ohio. She dissolves away the bone from the coal by means of dilute hydrochloric acid. Photographs and squeeze casts are then taken from the molds or impressions in the matrix. See also Bulman (1926).

Dr. F. A. Bather (1908) suggests coating the exposed parts of specimens with cellulose acetate before immersing them in acids. This tends to prevent the acid from dissolving the fossil. He also recommends the use of "Hypo-acetine," which, he says, has a more equable action on matrices containing calcium carbonate.

The chitinous tests of eurypterids and other invertebrates may be removed by applying a thick dab of Canada balsam and then dissolving the matrix with acid. The test sticks to the balsam and can be studied with transmitted light, like a dried skin. Preparations of this sort may be seen in Dr. Wiman's Museum, at Upsala.

Hanna, in his section of this manual, describes a way of removing thin scales of siliceous or ironstone matrix from invertebrate material with the concentrated heat of a small oxyacetylene torch. The heat is applied only long enough to cause expansion in the matrix coating, which is then plunged into cold water to crack it off. In applying this method to vertebrate material, the difficulty is that the surface of the bone often tends to flake off with the matrix.

After the specimen has been prepared and numbered, it receives a coat or two of thin shellac. This should penetrate the bone, and if a shiny surface is left on the specimen it should be wiped off with alcohol or steel wool. Old mounted skeletons which show signs of deterioration may be reshel-

lacked, and recent skeletons can be given a fine "eggshell" surface by shellacking them twice and rubbing lightly with steel wool after each coat is allowed to dry.

The bugbear of museum curators is an insidious chemical reaction known as "pyrites disease" which gradually destroys specimens that otherwise seem to be well prepared. The cause of this trouble is the oxidation of pyrite and marcasite minerals within the cavities of the fossil bones, a reaction which creeps through the skeleton like a fungus. The bones swell up and break apart, sometimes into thousands of small fragments. Pyrites and marcasites are found most commonly in material from beds of clay, sand, and shale containing iron and sulphur; but not all such material is affected. It is scarcely possible to remove the pyrite when it lies deep within the bone, but thorough shellacking or other treatment after drying in an oven may keep air and damp from penetrating. The great collection of mounted dinosaurs (*Iguanodon*) in the Museum at Brussels has recently begun to break down under the ravages of "pyrites disease." It has been necessary to dismount the entire group, clean out the skulls and bones, recement them, spray and dip them in great tanks of shellac, and bake them in ovens. A chemical method of removing pyrites and marcasites is described by Udluft and Matern (1926). E. Radley (1929) and Bannister (1934) discuss various means of preserving pyritized fossils.

Modeling

Sculptured restorations of fossil animals, as well as copies of skeletal parts, are useful and effective for classroom and exhibition purposes. The work is usually done in "plasteline," the imported Italian grades being the best. Clay has the disadvantage of having to be kept moist. A stand or armature of wire and wood is set up, somewhat smaller in all its dimensions than the completed study is to be. The modeler then outlines the dimensions of the object on paper with the use of proportional dividers or with a dioptograph or pantograph.

He then proceeds to duplicate the forms of the skeletal parts in his clay or "plasteline." After these are completed, he attempts to restore the musculature, skin, and other parts, according to his knowledge of anatomy and the appearance of living animals.

The model, when completed, may be cast in plaster, papier-mâché, bronze, or terra cotta. Terra-cotta casts have been made for us in a porcelain factory in Berkeley in the following manner. The "plasteline" model is first molded in plaster. A thin mixture of chemically treated clay is poured into this mold. The clay stiffens quickly when it comes in contact with the mold, and the liquid "center" is poured away. Removal of the mold leaves a delicate shell of moist clay, which, after setting, is fired in a furnace at a temperature of over 2000° Fahrenheit for three days. The result is a hard, very light, and durable reproduction. Allowance for a shrinkage of one-eighth of the linear dimensions may be made in the model.

Other methods of plastic reconstruction are discussed by Strasser (1887), and Koch (1913).

Casting

Specimens may be duplicated by casting them in plaster of Paris. The best grade of dental plaster, or a very hard plaster known as "Hydrocal," may be used, both for the plaster mold or negative and for the cast. An expert will be able to get a permanent plaster negative from almost any specimen. Undercuts are molded separately; sometimes as many as ten pieces may constitute the entire mold. It is usually greased with lard oil, or with a mixture of equal parts of lard oil and liquid soap, before the cast is poured.

Good results may be obtained from glue molds. These are easier to handle, but they are not permanent and will break down after eight or ten positives are taken. Also, the glue mold is not suitable for reproducing a "plasteline" model, because some kinds of "plasteline" will melt under the heated glue.

The simplest type of glue mold is made by pouring a thick mass of hot glue all about a specimen supported in a box or frame. When cooled, the glue mold is cut away from the specimen and is then poured full of plaster. Usually it is best to provide an outer support for the glue. This is done by enclosing the model or specimen in a clay envelope which is rounded to prepare for taking a simple plaster cast. Then the clay envelope is cast in a two-piece plaster jacket. The clay from one half of the specimen is removed and the glue is poured in through the holes left for this purpose in the plaster jacket. When the glue cools, the specimen is freed from it and a little powdered alum or alum water is spread over the surfaces of the glue mold to cure and harden the glue. This process is then repeated for the other side of the specimen, thus producing the two halves of a glue mold into which plaster may be poured to complete the cast (Hermann, 1909). Hermann also recommends the addition of dextrin to the casting plaster, as this gives a more durable result. It also tends to slow down the setting rate of the plaster, a valuable item in reconstruction work. The dextrin is dissolved in boiling water, about one pound to three quarts of water. This solution is then used to mix the plaster. Plaster sets slower when it is not stirred.

Success in making good glue molds and casts depends in large measure upon the experience of the technician. The procedure at present followed in our laboratory is as follows.

Supplies.—Potter's or modeling clay; thin boards for plaster frame; ordinary plaster for jacket around glue mold; petrolatum, lard oil, or axle grease and kerosene to lubricate the specimen and edges of the mold; rubber bands cut from an old inner tube for tying plaster jackets together; tissue paper for separating specimens from the clay; shellac to spread on the plaster jacket; double boiler for glue; alum water to harden the glue, should the chemical heat of the plaster start to melt it; fine talc to prevent the jackets from sticking to the glue mold; a supply of cooper's glue or "Mikah" casting gelatin for the mold.

First step.—Build a clay bed for the specimen by spreading a layer of wet clay less than 1 inch thick on the table or on a smooth board. Place the specimen on the clay bed and build up more clay to enclose the lower half of the specimen, being sure to fill out all undercuts, and provide a surface of low relief from which the plaster jacket may easily be lifted away. Leave a border at least 2 inches wide on the original clay platform for the margins of the upper plaster jacket. Work over the clay with wet hands so as to produce a smooth surface.

Second step.—Cover the exposed part of the specimen and surfaces of the clay with a layer of dry tissue paper. Roll out a flat sheet of clay about ¾-inch thick and lay this over the upper half of the specimen, pressing it down into the cavities and building up all undercuts. Leave about 1½ inches of the 2-inch margin on the lower clay envelope. Shellac the surface of this clay and, when it is dry, apply a grease coating.

Third step.—Nail four boards together to form a frame around the clay-enclosed specimen. Leave no openings in the joints. Mix and pour over the clay jacket enough plaster of Paris to make a jacket between the specimen and the frame. Reinforce the plaster with iron rods laid on horizontally and allowed to project a little beyond the edges of the boards. After the plaster sets, knock away the board frame and lift the jacket away from the clay.

Fourth step.—Remove the top section of clay and paper. Shellac the lower clay envelope. Let the shellac dry and grease the exposed part of the specimen and the lower clay envelope. With brace and bit, bore a hole 1 to 1½ inches in diameter through the top of the plaster jacket. This is the hole through which the glue will be poured. Also, be sure to have some smaller holes for air vents, to prevent bubbles in the glue. Clean and shellac the inner surface of the jacket and grease it. Now put the plaster jacket over the specimen again, seal the outer edges around the bottom with clay, and weight it down. Melt the glue until it is free from lumps and runs

smoothly. Add water or glycerin if desired. Remove the glue from the fire and keep stirring to prevent formation of a film on the surface. Pour the glue through the large hole in the top of the jacket. When the glue begins to show at the vents, plug them and allow the glue to set until cold. When the glue has set, turn the whole block of plaster, clay, glue, and specimen upside down. Remove the clay base. Replace it with a smooth clay envelope separated from the specimen and the glue, as in step 2. Build up another frame, fitting tightly around the edge of the first plaster jacket. Pour a second plaster jacket and then pour the other half of the glue mold as in steps 3 and 4.

Fifth step.—Remove the top plaster jacket. Remove the top section of the glue mold from the specimen, cutting it if necessary with a sharp knife or razor blade. Remove the lower jacket and glue mold in the same way. Now make an opening in the glue molds and in the edge of one of the plaster jackets so that liquid plaster may be poured into the cavity of the glue molds. Cut other small vents to prevent formation of enclosed air spaces when the plaster is poured. Sprinkle the glue mold with talcum powder (tire talc) to prevent it from sticking to the jackets. Shellac the edges of the plaster jackets and grease the inside of the glue mold. Fit both jackets together, with their enclosed glue molds, and bind them with thick rubber bands attached to the projecting iron rods.

Sixth step.—Mix a good grade of dental plaster or "Red Top" plaster with water until it will pour readily but not too freely. Pour this into the mold and plug the vents when the plaster appears in them. Fill up and allow to set. Then lay the jackets on their edges, remove the rubber bands, separate the jackets from the glue molds, and carefully lift the glue molds from the positive cast. Should the heat of the plaster tend to melt the glue, sprinkle the mold with alum water to harden it. After removing the case, clean and regrease the molds and repeat the process to get duplicate casts.

After completing the casts, cut the glue into chunks and spread these out to dry for re-use; otherwise the glue will become moldy.

A precaution.—When the second half of the glue mold is poured, the hot glue may tend to fuse with the cold surface of the first half. To prevent this, put a little oiled tissue paper on the cold surface under the hole through which the hot glue is to be poured. Also, let the hot glue cool a little before pouring.

Mention has been made of the so-called casting gelatin known under the trade name of "Mikah." This is a good grade of glue distributed by the National Adhesive Corporation. It may be mixed in the ordinary way with water in a double boiler and heated and stirred until the lumps disappear. The viscous liquid is then allowed to stand for about twenty minutes until the bubbles rise to the surface. The bubble froth is then skimmed off and the glue is ready to pour into the mold.

Ordinary glue molds are not permanent and usually will not stand up for more than ten positive castings. They also dry out quickly. Mixtures of glue and glycerin, and other materials, may be used which allow the preservation of the mold if this is desired. Such a "negative material" is procurable from A. K. Peiler, 4048 Brown Avenue, Oakland, California.

Glue casts (and molds as well) which will remain permanently flexible can also be prepared by mixing glycerin with the heated glue. The dry glue is placed, with a very little water, in a double boiler. Glycerin is added drop by drop, with constant stirring, until the amount of glycerin added is equal to the amount of glue. A little corrosive sublimate may be added to prevent molding. If a light-colored cast is desired, mix some white-lead powder into the mass.

A casting medium which is flexible, durable, and very tough is the raw form of rubber known as "liquid latex." This becomes viscous when heated and cools slowly, to provide a negative which may be pulled out of foramina and cavities

without breaking off. It may be used to cover large specimens in a thin envelope which may be enclosed in a plaster case before the positive casts are taken (cf. Marchionna, 1933).

"Squeezes" are useful quick casts made by pressing putty, "plasteline," warm wax, paraffin, or gutta-percha into impressions left by bones, or over the bones themselves. Gutta-percha (or caoutchouc) is the most permanent material and gives a remarkably exact and durable image of the original. The substance is obtainable in sheets about ¼-inch in thickness. A piece slightly larger than the surface of the specimen to be cast is laid in a cloth and soaked in very hot water until it becomes quite soft. It is then laid on the specimen and pressed firmly into all the crevices. When the cast cools, it is lifted away and allowed to harden before being handled.

To photograph the dark surface of the gutta-percha, the cast may be fumed with ammonium chloride (see p. 50).

A plaster cast or squeeze will be more permanent when plated with nickel or copper by electrolysis.

Patented casting compounds such as "Negocoll," "Hominit," and "Celerit" have the advantage of being extremely sensitive to faint impressions of fine details. Most of these compounds are expensive, they shrink rapidly when drying, and some of them break apart too readily. The use of "Negocoll" is described by Schelenz and Frentzen (1929) and by Poller (1931); see also *Scientific American*, 1933, page 123. Some workers use "Negocoll" for negative casts and dental plaster for the positives.

Tracks and trackways which cannot be easily removed may be cast in plaster or paraffin. A record should be kept of the orientation and distances between the individual tracks, with photographs and diagrams. The tracks should be washed and brushed out and greased with oil or vaseline before the plaster is poured. Lighter casts of large tracks may be taken by pressing wet blotting paper into the tracks. When the paper dries it retains the form of the track. Squeezes of small tracks may be taken in gutta-percha or "plasteline."

Drawing

Accurate drawings are fundamental to descriptive work in paleontology. Crude drawings will continually have to be superseded by more accurate illustrations. The use of calipers, copying cameras, *camerae lucidae*, and other aids may give pronounced distortions, from parallax (fig. 28) and other causes. These errors can in large part be avoided with the use of a homemade dioptograph, which may be constructed

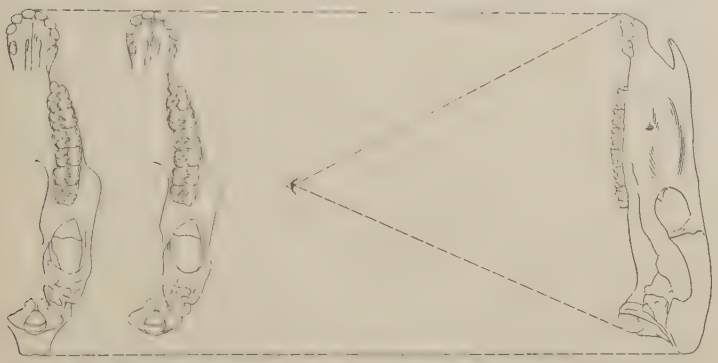


Fig. 28. Distortion caused by the phenomenon of parallax when a large object is drawn from a single point.

at small cost. The apparatus consists of a large box or cabinet built up from the floor and provided with a plate-glass top at waist level, 3 or 4 feet square. Strong lights are arranged in the box so as to shine obliquely downward on the specimen, which is placed on an adjustable shelf below the glass. The arm of an ordinary pantograph with a sighting tube in place of the usual tracer extends over the glass. By following the outlines of the specimen sighted through the upright tube, the pencil at the opposite end of the pantograph will trace the outline in convenient enlargement or reduction. If the object is to be drawn natural size, a simple extension frame (fig. 29) anchored at the center *c* with pencil at *p* and sighting tube at *e* is used in place of the enlarging and reducing pantograph.

For drawing small or flat objects when it may be unnecessary to avoid the parallax caused by use of a lens, a large copying camera with a clear glass back can be employed. The work is done in a darkroom and illumination is provided by installing two 100-watt light bulbs in reflectors, placed close to the specimen. The drawing is made on tracing paper or cloth placed against the glass. It is still more convenient to

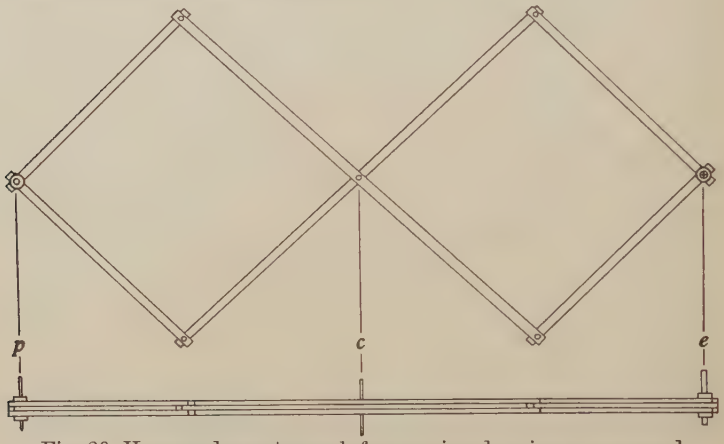


Fig. 29. Homemade pantograph for copying drawings, maps, and outlines of fossils in natural size. × ⅛.

have an apparatus which will project the image through a lens down onto a table. If an apparatus of this kind is set up in a darkroom, the lamps and specimen can be enclosed in a separate compartment, or under a hood. If the work is done in daylight, a canopy must be provided to shield the artist's table from the outside light.

Microscopic preparations can also be drawn by means of a camera or projector by removing the eyepiece (ocular) of the microscope and focusing the image from the objective directly on the camera ground glass or onto the table. Excellent photomicrographs can also be taken in this way, but the field will be smaller than when one is using a compensating lens in the microscope draw tube.

Another apparently simple method of avoiding parallax is described by Miss Innes (1927). She places the object on a piece of glass mounted 1 foot above another glass sheet which in turn is 1 foot above a table. A white cardboard reflector is placed over the specimen and illumination is provided by a strong movable lamp. The drawing is made on thin, dark, tracing paper placed below the lower glass. The drawing is kept in register by means of a dot or cross of ink placed on the lower glass and kept over one spot on the reflection of the specimen.

For copying drawings, maps, and diagrams, a good grade of tracing cloth may be used. The copy on the tracing cloth may then be sent directly to the engraver to be photographed for publication. Good Bristol board is generally used for drawings, but recently an opaque, white, sheet celluloid has been recommended (Weston, 1935). A most useful treatise on the art of scientific illustration and the reproduction of illustrations will be found in Ridgway (1920). Figgins (1931) emphasizes the need for standard viewpoints in illustrating horned and antlered skulls. Reeside (1930) gives valuable information on the preparation of photographs of fossils. See also Stibbe (1930) and Williams (1917).

Photography

In ordinary photography, it is convenient to use a camera stand, such as a heavy, upright pipe, or a tilting-top tripod, which will allow the camera to be pointed downward (Moodie, 1915). Large reflectors on stands carrying high-power lights; reflecting screens of white cloth or flexible metal; background drops of white, neutral gray, and black velvet are all handy accessories. Help in the choice of camera and equipment, composition and lighting, and darkroom technique may be found in numerous works on the subject, particularly Adams (1935), Hay (1930), and Neblette (1935).

E. A:son Stensiö has discovered a way of photographing fossils under refractive media so as to bring out contrast,

surface structures, and details. He places the specimen in a dish and floods it with xylol or oil of aniseed. The latter evaporates more slowly and there is not the danger of ignition or explosion under the heat of the arc lamps which illuminate the work. The photograph is taken with a long-focus lens, a small stop, and an extended exposure of several hours. Illumination is provided by automatic arc lamps directed through water cells, or by powerful microscope lamps with reflecting shades (Stensiö, 1927).

Dark or discolored fossils may be treated with fumes of ammonium hydroxide and hydrochloric acid to give them a white coating of ammonium chloride. Bind together two test tubes provided with rubber stoppers and glass tubes (fig. 30). Fill one tube half full of HCl, and in the other tube pour NH_4OH. Blow into the open ends of the longer tubes and let the vapor (NH_4Cl) issuing from the spouts of the shorter tubes settle over the specimen. The work must be performed in a dry atmosphere. This coating may easily be removed when the photographing is finished (Moodie, 1915). The method is particularly useful with fossil shells. Cooper (1935) has suggested improvements in the ammonium chloride apparatus, particularly the use of an electrically heated tube for the production of the vapor.

"Negative photographs" of skull cavities have been introduced by Edinger (1925) to show the topography of the brain surface in relief without the trouble of making brain casts. These photographs can be made directly by using high-speed enlarging paper in the plate holder of the camera.

The use of ultraviolet fluorescence in the study and photographing of fossils has scarcely received the attention it deserves. By its use, it is said, obscure sutures can be traced, determinations of delicate structures can be made, and many other applications are possible. A summary of the literature on the subject is given by Radley and Grant (1933). See also Möskes (1931), Seegert (1929), and Wagner (1928*a*, *b*).

Photographs of fluorescing objects placed upon a source of

ultraviolet light may be taken with an ordinary camera and lens. The source of illumination can be provided by a commercial ultraviolet lamp or by a gas tube constructed in helical form from one of the special types of glass (e.g., "Wood's

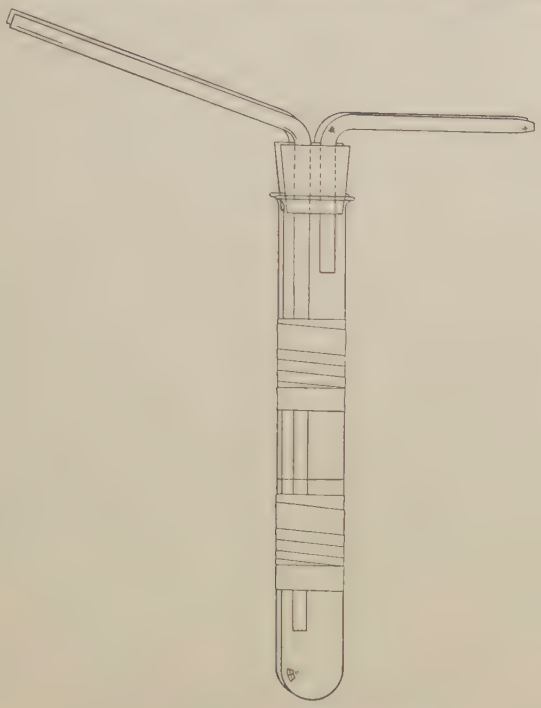


Fig. 30. Smoke-producing apparatus.

glass") now being manufactured to illuminate fluorescent advertising signs. Photographs published by Miethe and Born (1928) show obscure details brought out by the use of this method in fossil fishes. Lambrecht (1928*a*, *b*) has used the process to photograph minute muscle fibers in the wing membranes of pterodactyls.

The use of infrared light in the photography of fossils, particularly fossil plants, is discussed by Leclerq (1933).

X-ray photography brings out the inner structure of bones, the roots of teeth in mammals, and on unprepared specimens it will locate parts buried in thin shale. Hospital and college laboratories provided with X-ray equipment are usually glad to coöperate when such photographs are needed. Branca (1906), Fischer (1914), Hartmann-Weinberg and Reinberg (1925), Lehmann (1934, 1937), and Peyer (1931, 1934) give examples and discussion of results obtained by X-ray photography.

Sectioning of Bones, Teeth, and Wood

Study of the microscopic structure of fossil bone is still in its infancy. Sometimes important clues to the identification of fragmentary material may be made by comparison of thin sections (cf. Gross, 1934, and Nopsca and Heidsieck, 1933, 1934). These sections are made by sawing off a part of the material with a diamond saw, polishing one side and fastening it to a microscope slide with balsam, and then grinding it down to microscopic thinness on a revolving stone or lap (for references see p. 125). Soft bone may be rubbed down by hand on a glass plate, with "400" emery powder and water. When thin enough to transmit light, the section is protected with a thin cover glass (cf. p. 122). A polarizing microscope is recommended for the study of thin sections. Aeby (1878), Carroll (1929), Little (1903), Murata (1935), Schaffer (1893), Seitz (1907), Walkhoff (1901), and White (1891) have described the sectioning of bones and teeth.

Sections of fossil wood are made in the same manner. Some woods replaced by chalcedony are so hard as to require carborundum or diamond dust on the lap. Attempts have been made to take cores from fossil tree trunks with a diamond drill operated by a portable gasoline motor. By this method the growth rings might be preserved and studied without removing the heavy trunks, but operation of such a drill has so far been unsuccessful.

Polished surfaces of bone, wood, coal balls, and the like may be studied directly under the microscope or they may be

etched slightly with weak acid and "stripped" with celloidin. This is done by pouring over the etched surface a thin coat of cellulose acetate slightly stained with eosin. When this hardens, it is stripped off and mounted under a cover glass or on a lantern slide. Pollen grains and other fine structures can be examined directly from the impressions on the celloidin strip. Fossil leaves may sometimes be removed from their matrix by this method.

Darrah at Harvard uses, instead of cellulose acetate, a more flexible and peelable mixture: "Parlodion," 40 gm.; butyl acetate, 400 cc.; castor oil, 3 cc.; and xylol, 30 cc. With this compound he has obtained thin peels of wood structure a foot or more in diameter, which he has used principally for measuring and comparing growth rings in sub-Recent, semicarbonized wood. It is unnecessary to stain the celloidin when the subject contains carbonaceous material, because enough of this is transferred to the "peel" to give contrast.

For further notes on the use of celloidin peels and impressions, see Butler (1933, 1935), Fenton (1935), Graham (1933), Koopmans (1928), and Mercier (1929). Mercier suggests the addition of glycerin when an opaque, white, celluloid film is desired.

Serial Sectioning

Reconstruction of small fossils by grinding off thin, measured thicknesses of the bone, drawing the successive sections, and building these up like a relief map is a method introduced by Sollas (1903) in his study of *Dicynodon, Lysorophus,* and *Paleospondylus.* The machine used by Sollas was complicated and expensive. We have obtained good results with a simpler apparatus constructed in 1931 by VanderHoof (fig. 31).

Essentially, this machine is a heavy brass box open at the base and fitted with a plunger operated by a finely threaded screw. The fossil is carefully oriented and embedded in a plaster block set within the box, the sides of which are smeared with vaseline to allow the block to be pushed slowly downward during the cutting of the sections. The pitch of the screw

is such that a movement of as little as $\frac{1}{10}$-millimeter can be registered on a dial cut below the handle of the screw. The grinding is done on a small power-driven belt of "00" emery cloth moving over a flat stand. The box is held against the

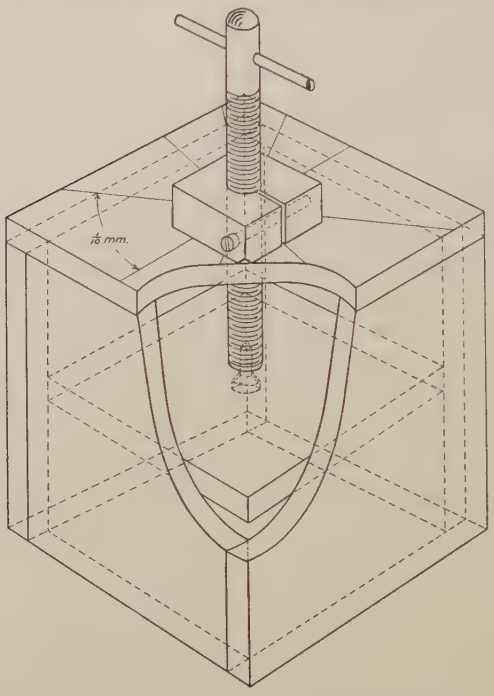


Fig. 31. Machine for cutting serial sections.

moving belt and removed when the plaster block is found to be ground down to the edges of the box. The section is then drawn in an enlarging camera, and selected sections may be photographed or "stripped" with celloidin. The drawings are transferred to cellophane or beeswax plates (a mixture of beeswax and paraffin is good) of constant, known thickness. These are cut out and cemented together so as to form an enlarged model of the subject.

A similar apparatus has recently been described by Simp-

son (1933); Koslowski (1932) also gives a simple method of cutting serial sections. Stensiö, in his laboratory at Stockholm, embeds the specimen in a block of hard dental plaster and grinds off the sections by hand on a thick glass plate moistened with a "mud" of the finest carborundum dust. The thickness removed is controlled by a machine gauge reading to $^1/_{1000}$-millimeter. Small irregularities disclosed by the gauge are ground down by hand with carborundum "mud" daubed on the ends of short glass rods or glass bottle stoppers. The section is then coated with balsam, to bring out the details, and is drawn under a vertical projection apparatus (see p. 48). The finer details are added to the outlines by means of a *camera lucida*. The projection apparatus should remain set while the sections are being drawn, as it is difficult to bring it into register. For further notes see Bulman (1925, 1926).

Cataloguing

One of the most necessary precautions in the care of a fossil collection is order. There is great danger that parts of specimens may become lost or separated, and loss of data accompanying a specimen almost entirely destroys its scientific value. Cataloguing by some definite system is necessary; it matters little what system is selected, so long as it is *followed*. Herewith is an outline of a card-index system in use in the Museum of Paleontology at the University of California. This is a quadruplicate system based on a catalogue described by Walton (1907).

When a shipment of fossils arrives, it is labeled with an *accession number*. This number is then entered on an *accession card* (fig. 32*a*), which is filed in a drawer reserved for this purpose. On the card are spaces for recording the dates of collection and receipt of the shipment, the nature of the material, the name and address of the collector and the shipper, the locality, the locality number and the series of specimen numbers eventually given to the collection, and the date of entry of the record with the name or initials of the cata-

d

Systematic Catalogue—VERTEBRATES

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY

Case No. 4

Name *Hipparion lenticulare* Drawer No. 98-4

Mus. No.	Loc. No.	Place	Acc'n No.	Material
30581	V2823	Hemphill, Co. Texas	24	4 upper cheek teeth
30582	"	"	"	metacarpal

Numerical Catalogue—VERTEBRATES

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY

Acc'n Nos. 24 Date of Entry Aug. 10, 1932 Entered by Curtis J. Hesse

General Locality V2823: Pliocene of Hemphill County, Texas

Mus. No.	Name	Date	Collector	Obsc. No.	Loc. No.
30581	Hipparion lenticulare	1928	R.A. Stirton	Field no. 301 P.R.S.	V2823
30582	" "	"	"	" 315	"
30583					
30584					
30585					
30586					
30587					
30588					
30589					
30590					

c

LOCALITY CATALOGUE

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY

Loc. No.	1st Acc'n No.	Description of Locality
V2823	24	Pliocene of Texas
		"Quarry 20", N.E. corner of Sec. 59; block A-2,
		Hemphill, Co. Texas. 500 ft. N. of old Miami to
		Canadian highway. 8.5 by road N.E. of Miami
		Courthouse, and 1.5 mi. by road from Roberts-
		Hemphill county line. On Clyde Coffee ranch.
		Quarry in base of "white" or No. 1 bed of Reed &
		Longnecker survey, Reed's original locality 20.
		See: Field notes- Camp, 1928- p. 1081-1085;
		Stirton- 1928 also 1932; Univ. Texas Bull. no. 3231.

b

ACCESSION CATALOGUE

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY

1m-12,'30

Date Rec'd July 1st, 1932 Acc'n No. 24

Nature of Material 10 boxes of fossil mammals

Rec'd from R.A. Stirton How Obtained collected, U.C. party

Address Miami Texas

Correspondence See: Stirton Field Notes Stirton-1932

Collector A.J. Geer; O.J. Poe; N. Geer; R.A. Stirton When Collected May-July-1932

Locality and Loc. No. V2823- "Quarry 20" of the Reed & Longnecker geological survey; 11mi. E. of Miami, Texas

Catalogue Nos. 30570 to 30889; 31071 to 31130

Remarks Entire collection made of one locality

Date of Entry July 10th 1932 Entered by Curtis J. Hesse

1m-12,'30

a

Fig. 32. Catalogue cards: *a*, accession; *b*, locality; *c*, numerical; *d*, systematic.

loguer. Besides, there may be included the name under which pertinent correspondence is filed; the method by which the material was obtained, whether by gift or purchase, or collected by a field party; a reference to the field notes and photographs available for the collection; and such other remarks as may seem useful. The information on this card, if entered as soon as possible, insures against loss of data on unprepared specimens which may have to be set aside for a time. The accession number may of course refer to a single specimen or to a large shipment of material.

As soon as a specimen is sufficiently cleaned, it receives its *locality number,* written on it in waterproof ink and shellacked. This number is entered, preferably by the original discoverer of the locality, on a card (fig. 32*b*) which is filed in the *locality card catalogue.* The data on this card should be drawn up carefully to include the exact geological horizon, and the exact geographic locality with reference to a map and to field sketches or photographs in a field notebook. The entry also gives a reference to the first accession number from the locality. In our system, the V indicates a vertebrate locality, the next two numbers refer to the year the locality was discovered (i.e., 1928), and the last one or two numbers record the order of entry of the locality in that year. V2823 is, therefore, the 23d locality entered in the vertebrate catalogue for the year 1928.

Many specimens of secondary value, which will not be figured, referred to individually, or used as types, are left with the locality number only. Materials of more importance receive also a *specimen number*—sometimes called a "museum" or "catalogue" number. This is written below the locality number and separated from it by a line. It is put on the specimen at the time the latter is fully prepared and ready for study, storage, or exhibition. It is entered at once in its proper numerical sequence on one line of a *numerical catalogue* card (fig. 32*c*) which contains also the accession number, the date of entry, the cataloguer's name, the scientific name of the

specimen (in pencil if not yet fully determined), the date of collection, the collector's name, his original field number, and the locality number.

After the specimen has been studied and has reached its place in the museum, its museum number is entered on a card in the systematic catalogue (fig. 32*d*). Here it is placed under its systematic name, its location in the museum is recorded, and its locality number and general locality are again given, as well as the accession number and the nature of the material. The systematic catalogue is arranged for reference under a conventional scheme of zoölogical classification.

We find that this system preserves, by several cross checks, all pertinent data on the specimen. It is safer and more compact than the usual system of writing out data on individual cards for each specimen, and takes less time than does the writing of individual cards.

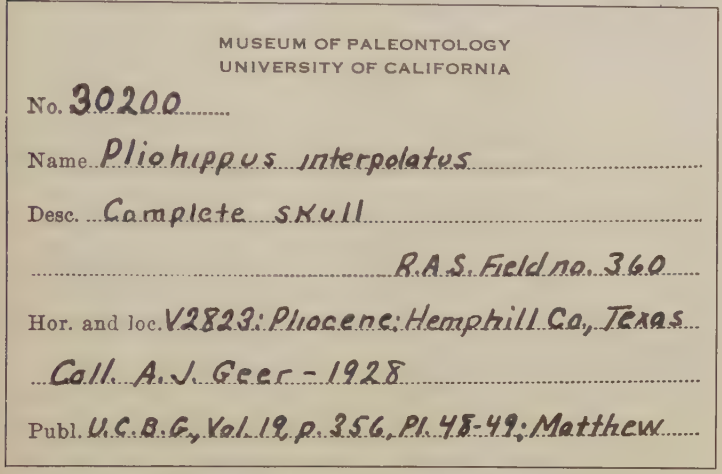
Storage

Specimens fully prepared are laid away in trays placed in drawers set in racks. The final storage should combine accessibility, dustproofing, and fireproofing, and should insure against mixing, breakage, and earthquake damage, so far as possible. Steel cases with locked doors are almost ideal but expensive. We use these for types and for the more valuable material. Wooden racks and cleated drawers contain the greater part of the collections. These are fitted with sliding, plywood front panels and each rack is labeled with an outside number and a placard referring to the contents. The racks are arranged according to geologic periods, and collections from each locality are kept more or less together.

Each drawer has, tacked to its front, a small brass card holder containing a removable card with the number of the drawer and an indication of its contents. The specimen, if large, is tagged with a string tag and laid in the drawer. If small, it occupies a pasteboard tray or vial containing a tag or label (fig. 33) on which is written the museum number, the

name, the nature of the specimen, the collector and his field number, the locality number, the geological horizon and locality, and a reference to a published description, if any.

Types receive special care. The data concerning them are written on individual red cards for the *type catalogue*. These data are repeated on two labels, one pasted on the outside of


MUSEUM OF PALEONTOLOGY
UNIVERSITY OF CALIFORNIA

No. 30200

Name Pliohippus interpolatus

Desc. Complete skull

R.A.S. Field no. 360

Hor. and loc. V2823: Pliocene: Hemphill Co., Texas

Coll. A. J. Geer - 1928

Publ. U.C.P.G., Vol. 19, p. 356, Pl. 48-49; Matthew

Fig. 33. Label for storage specimen.

a closed pasteboard or small wooden box, the other laid with the specimen in the box. These labels and the specimen receive, each, a gold diamond sticker for the type of a species, two for the type of a genus. A figured specimen receives a circular gold sticker, so that it may be distinguished more quickly. Loss of types and figured specimens is unfortunately all too common in large collections.

Use of Material

Specimens, to be made available for handling, should first be prepared as sturdily as possible, reinforced plaster being used inside the skulls, and iron rods inside the limb bones, to prevent breakage. A specimen taken from storage for

study, class use, or loan to other institutions should be replaced by a colored label indicating the disposition made of it. Fragile material should not be handled more than absolutely necessary, should not be used in classrooms unless enclosed in glass-topped boxes, and should go out only to specialists, for research purposes.

Fig. 34. Left hind leg of an oreodont, *Merychochoerus proprius,* as mounted at the American Museum of Natural History.

Exhibits

The mounting of large articulated skeletons is a job for the highly trained technician, and he should work with a specialist on the anatomy and pose of animals. Modern methods avoid the use of obtrusive, clumsy supports; the practice now obtaining is to resort to a light steel framework, welded with an acetylene torch, or by the electric arc, or by the resistance ("spot welding") method. The supports follow the courses of the limbs and vertebrae and are almost unnoticeable (figs. 34–36). In mounting fossil elephants, much trouble is often had with the tusks, which tend to crack and break to pieces even when thoroughly soaked in shellac. The ivory, being impervious, will not absorb ordinary hardening fluids; but perhaps treatment with

Fig. 35. Wolves and saber-toothed cat from Rancho La Brea, mounted in the laboratory of the Colorado Museum of Natural History by Mr. Philip Reinheimer, who stands in the picture. Specimens from collections of the University of California.

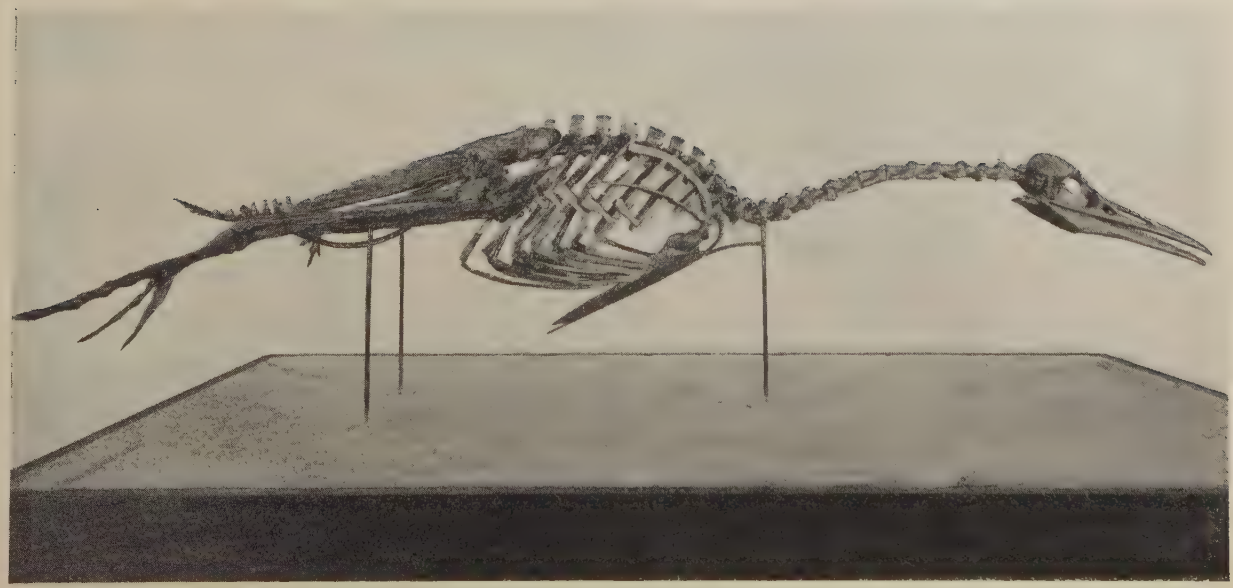


Fig. 36. Cretaceous toothed bird, *Hesperornis*, as mounted at the American Museum of Natural History.

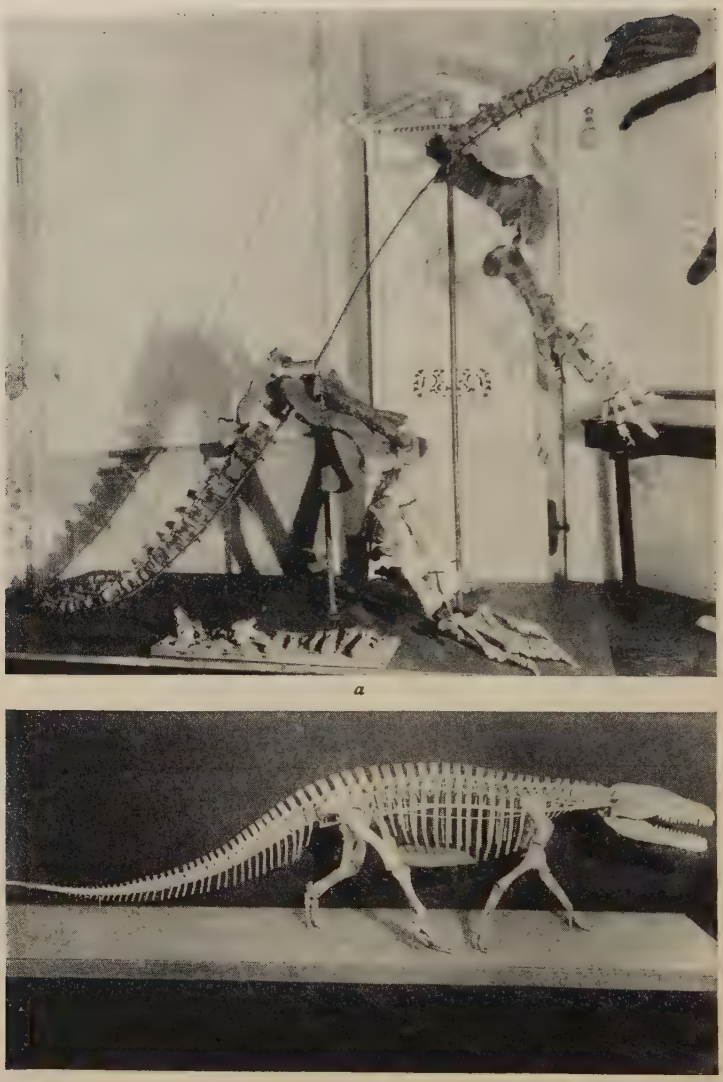
"Bakelite," under pressure, would solve the difficulty. The usual scheme has been to bind the tusks with unsightly copper wire or bands.

Upright mounts can be constructed, as Huene has done at Tübingen, in such a manner as to allow removal of all parts of the skeleton for study (fig. 37). The mount is made of steel rods or tubing with U-shaped claspers of spring steel welded to the framework to receive the vertebrae, girdles, limb bones, ribs, and foot pieces. The skull is arranged so as to be detached as a whole. Detachable mounts can also be set into a flat plaster base with cavities to receive the elements of the skeleton. See Drevermann (1930), Gilmore (1932), and Strunz (1928).

Stehlin, at Basel, hangs large skeletons with invisible piano wires in plate-glass cases. In setting up this or any other kind of free mount, it is often useful to swing the bones from a temporary frame with cords or hooked wires which can be lengthened or shortened and moved about as required. The pose and articulations can then be more easily adjusted so as to obtain a correct and lifelike pose.

Lull, at Yale, and Figgins, at the Denver museum, have constructed lifelike free mounts in which one side of the animal is modeled in plaster or papier-mâché so as to show the original appearance of the surface of the body. The other side is left open, to display the bones of the skeleton.

Carrying this idea in another direction, habitat groups have been constructed in which restorations in plaster, built from careful studies of the skeleton and musculature, are grouped together in a case furnished with accessory models of plants and other features of a primeval landscape. The background is painted on a flat canvas, or preferably on a curved background which can be made to blend into the features in the foreground. Blending is accomplished by turning down the base for the foreground until it disappears from sight, or by placing some of the three-dimensional elements of the foreground on the background canvas (fig. 38*a*, fig.



a

b

Fig. 37. *a*. Triassic dinosaur, *Plateosaurus,* mounted under the direction of Professor F. von Huene, showing form of metal supports for detachable bones. *b*. Triassic reptile, *Prestosuchus.* The bones are cast in plaster and mounted on clips so as to be removable.

38*b*). The glass front of the case if tilted slightly back at the base avoids reflections and gives the exhibit a more lifelike appearance.

Interesting habitat groups of fossil invertebrates have been constructed by Dr. R. Ruedemann (1931) at the New York State Museum, at Albany. See also Abel (1925) and Knight (1935).

Moving pictures, such as "The Lost World," show dinosaurs, pterodactyls, and other extinct animals as they may have moved and acted in life. These are habitat groups in motion—unforgettably realistic if one is able to disregard the anachronism of human figures introduced into the Age of Reptiles. The pictures are made by photographing miniature groups of animals, modeled in flexible "plasteline," against painted and modeled backgrounds. The figures are moved very slightly between each of the thousands of exposures; requiring a long time for the completion of a picture. It took a year to photograph "The Lost World."

The "panel mount" is one of the least expensive and most effective ways of displaying a specimen. The fossil is prepared and left in its original position, as it was deposited in the rock. If desired, it may be prepared on both sides and mounted in an opening cut to accommodate it in the plywood plank. Strips of heavy, small-mesh, wire netting are nailed securely to the cut edges of this opening. The netting is bent down over the edges of the hardened matrix or plaster in which the prepared specimen lies and is fastened securely with wires run through the netting and matrix. Plaster is then forced into the netting and spread over it between the specimen and the board. The result is an upright flat mount which can be viewed from both sides. Panel mounts usually show only one side of a specimen, and may be hung vertically or laid horizontally in cases. An interesting adaptation of this method has been used to display a fine, new group of Iguanodont dinosaurs at the Brussels museum. The specimens, in the attitudes in which they were found in the quarry,

Fig. 38*a*. Parts of habitat group showing restored landscape in the Chinle Triassic period in Arizona; Petrified Forest Museum in the Petrified Forest National Monument, near Holbrook, Arizona. The trees shown are monkey-puzzle pines, *Araucaryoxylon* and *Woodworthia*. The cyads and horsetails are restored from leaf impressions and petrified stems.

Fig. 38*b*. Parts of habitat group showing restored landscape in the Chinle Triassic period in Arizona. The phytosaurs, *Machaeroprosopus*, are modeled in the foreground and painted on the background. Group arranged under direction of the National Park Service and with assistance from the Museum of Paleontology at the University of California.

are mounted on four sides of a pyramid placed in a shallow pit and surrounded by a railing.

Fossil skeletons are sometimes too fragile to be supported as an upright free mount. These may be mounted on a plaster panel embedding one side of the skull and showing only the skeletal elements on one side. Or, the limbs and skull may be mounted free in a recessed panel and parts of the opposite

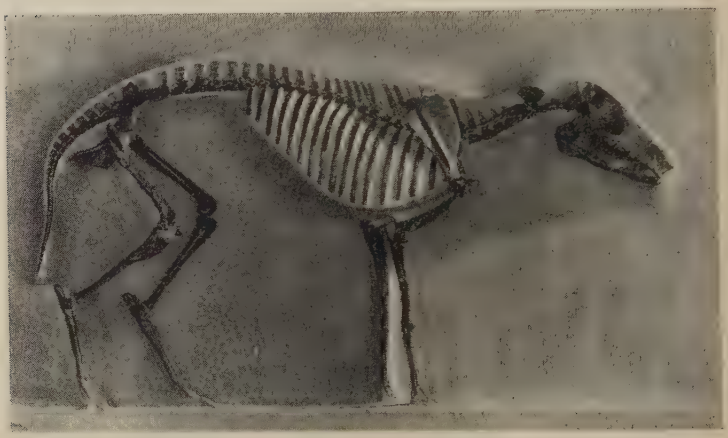


Fig. 39. Panel mount of an original skeleton of the primitive four-toed horse, *Eohippus,* from the Eocene of Wyoming, as set up at the American Museum of Natural History.

side may also be shown (fig. 39). Or, the more delicate parts of the skeleton may be supported in plaster as shown in figure 40. Very large skeletons, if too fragile for free mounting, may be cast or modeled in plaster and the casts may be set up in place of the originals (fig. 37*b*). One of the skeletons of the huge dinosaur *Brachiosaurus,* from Tanganyika, is being modeled for mounting at the Berlin museum. When completed, the skeleton will stand about forty feet high.

Consult Hermann (1909) for further details on the construction of mounted exhibits. It is frequently desirable to set up recent skeletons to accompany fossil skeletons in the classroom or museum. The technique of collecting, prepar-

ing, and preserving recent osteological material is described by Boettcher (1912), Lucas (1914), and Holden (1914, 1916).

The methods and styles of exhibiting fossils in public museum galleries will naturally follow the taste, means, and needs of the institution concerned. Many of the older museums in Europe have thought it desirable to place large

Fig. 40. Plaster mount of the Mongolian dinosaur, *Protoceratops,* at the American Museum of Natural History. The plaster imitates in color and texture the matrix in which the bones were found.

quantities of material in their exhibition cases, believing, no doubt, that the requirements of research workers and students are best served by having as wide a selection as possible on display. The arrangement of the specimens under glass may be according to the systematic classification, or to the stratigraphic—with the faunas of successive periods placed together.

Some museums have developed interesting exhibits showing biological and geological principles by means of groupings of fossil and recent material. It is possible to lay out

panels showing the evolution of such groups as the horse and the dog—illustrated by actual specimens or by casts of the skulls, teeth, and limbs, and diagrams and restorations of the body form.

Exhibits arranged to illustrate facts of comparative anatomy are instructive. The various types of teeth in the vertebrates, including both recent and fossil forms; the history of the skull and skeleton; the adaptive modifications of the limbs; interpretations of the evolution of the muscular and ligamentary locomotor structures as revealed by the skeleton—subjects of this sort are especially valuable in connection with classwork in university museums.

Some of the large public museums have given attention to the history of man so far as it is revealed by the fossil record. Habitat groups with restored models may be arranged on one side of a gallery. Opposite them casts of the known fossils may be placed, to show the material upon which the reconstructions have been based. The Field Museum, Chicago, has beautiful displays of this kind.

Local museums in districts where fossils are abundant may wish to specialize in complete displays of the material from their neighborhood. These local exhibits are of especial interest in the National Parks, frequented by numerous visitors who may spend only a short time in the region and who wish to appreciate more fully the geological history of the locality.

Whatever the nature of the exhibits, it is of prime importance to adopt a system of labeling which will tell the essential story briefly, simply, and attractively. Some exhibits require two or more labels; one of only a few words, as a heading, and another an explanatory statement consisting of two or three paragraphs. Then, too, each specimen should be fully labeled with name, locality, geologic age, and (if it happens to be original material) museum number. Labels should often be supplemented by photographs and diagrams (Lang, 1930).

A good housing for a small exhibit is an upright case with

plate-glass doors, front and back. Vertically through the center of the case runs a 1½-inch plywood plank into which brackets may be screwed to support small specimens in any position. The plyboard may also be perforated to receive panel mounts and specimens lying in their original matrix.

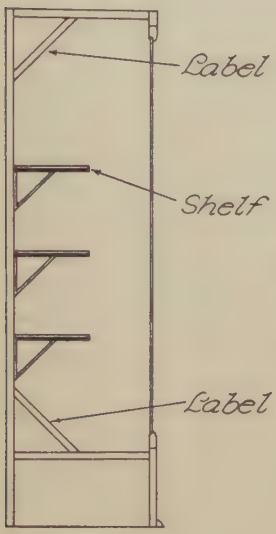


Fig. 41

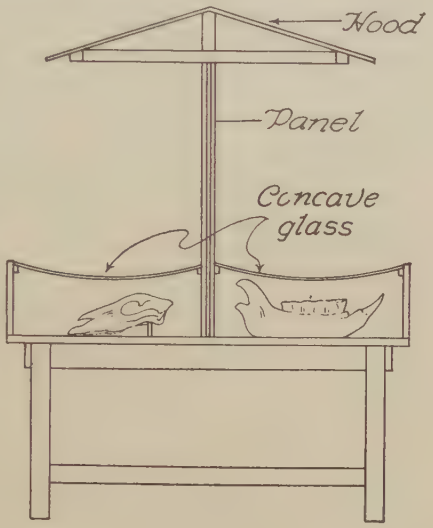


Fig. 42

Fig. 41. Section of an upright case with shelves for specimens, and tilted boards extending the length of the case at top and bottom to support labels.

Fig. 42. Table case with panel for labels and photographs. Note that it is fitted with a hood and with concave glass over the display sections in order to prevent reflections.

A modification of this type of case is illustrated in figure 41, in which the specimens are supported on shelves or brackets. Tilted label holders are arranged above and below the exhibit to bring the labels into easy view.

Ordinary table cases are more effective if provided with concave glass and a shading hood to avoid disconcerting reflections (fig. 42). Cases of this kind are in use in the Geological Museum, South Kensington, London.

NOTE ON PALEOBOTANICAL COLLECTING

Methods of handling special kinds of plant fossils are elsewhere noted in this manual. The collecting of fossil leaves may require no special precautions (Knowlton, 1927). Leaves, together with fruits, nuts, flowers, and other plant fossils, are not always easily found, since they are quickly destroyed when on the surface. They generally occur in fine-grained sedimentary deposits, where prospecting is usually necessary to disclose the best leaf-bearing layers. The delicate impressions may be split out and brought to the laboratory in blocks of matrix. Shellac or other adhesive material should rarely be used to coat the specimens, as the fine details will be obscured. Some types of fine shales, soft when first excavated, will harden in the air to a degree sufficient to allow transportation. Large fragile blocks may be enclosed in plaster by the methods described in this manual.

Deposits containing leaves are usually thin-bedded, and the matrix can be split along the bedding planes where the leaves occur. To do this neatly, Chaney employs a broad, spadelike chisel, the edge of which is driven gently into the seams of the matrix (fig. 4*f*).

A phase of plant collecting that has become of importance in stratigraphic studies is the work now being done by Elias (1935) on the seed husks of fossil grasses from the high plains region of Nebraska and Kansas. Elias finds these beautifully preserved and characteristic remains in Miocene and Pliocene sands and grits. The material is so abundant that floral zones can be recognized. Collecting is done by scrutinizing freshly exposed banks and excavations in the sand to discover the delicate fossils lying in place. The lip of a glass vial is then pressed into the loose sand below, and the specimen is allowed to drop into the vial.

Mason (1934), in his studies on the Pleistocene plant remains from various localities in California, has found it pos-

sible to collect and identify fragments of carbonized and lignified twigs, pieces of bark, leaves, cones, fruits, and seeds. The organic materials are separated from the matrix by soaking the latter in water and screening or sorting the residue. The specimens are then either dried or preserved in glycerin.

Plant and animal remains from asphalt deposits, such as Rancho La Brea, are cleaned in gasoline or distillate, which rapidly dissolves the sticky bitumen. Small material placed in cheesecloth sacks may be soaked in the gasoline and later screened and sorted. Larger specimens may be cleaned with a brush.

Halle and Florin, at Stockholm, have made beautiful preparations of the cuticle of plants from Eocene peat deposits by maceration with ammonia, bleaching with free chlorine, staining, and mounting on microscope slides.

Hanna, in the second section of this manual, describes methods of studying fossil pollen (p. 126). For further information on the recovery of plant material by maceration and other methods see Jurasky (1931).

Fossil wood may occasionally be confused with bone. Microscopic examination of polished sections will generally show either the thick-walled Haversian canals or the laminae and spongiosa of bone, whereas in wood the thin-walled vascular canals, often arranged in annular rings, will serve as marks of identification.

Fossil insects and arachnids are sometimes found in fine shales along with plant impressions. A famous locality is at Florissant, Colorado, studied by T. D. A. Cockerell. The insects, spiders, and lizards enclosed in fossil resin or amber occur chiefly in beds of that peculiar substance lying on the floor of the Baltic Sea. Storms dislodge lumps of the amber, which are then washed up on the beach. Faked material, in recent resin, has been sold to unwary collectors. The true fossils will disintegrate at once when dissolved from their translucent matrix.

Once in a great while it may be necessary to differentiate

between fossil horn, cellulose, and chitin. Horn, if preserved in its original state, will not dissolve in potassium hydroxide, and the cornified (keratin) cells will remain after the material is boiled in this alkali. Horn is found chiefly in the vertebrates, chitin only in the invertebrates. Chitin is without cellular structure and is identifiable by means of chemical tests. H. H. Wundsch gives particulars (*Handbuch biologischen Arbeitsmethoden,* 1927, vol. 9, pp. 1042–1047). The object is placed in a closed and darkened vessel containing a solution of "diaphanol" until fully bleached;—the time required is about twenty-four hours. After washing, it is then treated with zinc iodine chloride. The presence of chitin (or cellulose) will produce a violet color in the sample. If there is a chance of confusion with cellulose or tunicin (the epidermal covering of tunicates), treat a second sample with potassium triiodide and concentrated sulphuric acid. Cellulose (or tunicin) will turn blue; chitin will stain iodine brown. The exact formula of chitin is not known. It is a nitrogenous carbohydrate containing about 46.4 per cent C, 6.5 per cent H, 6.7 per cent N, and 40.4 per cent O. It occurs in arthropods, echinoderms, and other invertebrates.

Miss Steen (*Proc. Zoöl. Soc. London,* 1934, p. 496) has found that some forms of fossil chitin from eurypterids cannot be bleached. In testing this material she used the method proposed by Rosenheim (*Proc. Roy. Soc.* [B], vol. 76, pp. 398–400). The fossil material was ground up with concentrated hydrochloric acid and left for three weeks. After evaporation an aqueous solution of the residue was made; "the presence of the product of hydrolysis of chitin, glucosamine, . . . producing with Code's test a red precipitate of cuprous oxide."

PART TWO: INVERTEBRATES

BY G. DALLAS HANNA

PREFACE

THE APPLICATION of micropaleontology to oil-field development during the last few years has enormously increased the number of workers. Because the technique upon which the science depends for advancement is still evolving, the following account can only be considered as a progress report. Even so, some published descriptions of methods have doubtless escaped my notice, and others which are already in use in laboratories have not been made public. I am not familiar with some groups of fossils and my treatment of them is consequently deficient. I hope, however, that the references supplied will be found useful.

The various types of rock and the many fossils with which the paleontologist has to deal make necessary a fair amount of skill in many crafts. It will be years yet before rigorous rules can be laid down for the guidance of the uninitiated; experience is still the best teacher.

The term "invertebrates" is here considered to include all those animals which do not possess a notochord. Besides the usual multicellular forms included in a biological classification, it will also be convenient to treat the unicellular animals which normally possess skeletal structures adaptable to fossilization and certain simple groups of organisms which properly belong to plants. Because the processes of deposition and preservation as well as methods of collecting and preparing fossils in all these groups are somewhat similar, they can best be considered together.

I wish especially to express the greatest appreciation for assistance received from persons who have been associated with me for many years in field and laboratory, particularly Wm. B. Barbat, C. M. Carson, Clifford C. Church, Charles M. Cross, Herschel L. Driver, Marcus A. Hanna, Leo G. Hertlein, Merle C. Israelsky, and John L. Nicholson.

G. DALLAS HANNA

California Academy of Sciences, San Francisco,
December 20, 1936.

THE COLLECTION AND PREPARATION OF FOSSIL INVERTEBRATES

Macrofossils

Under the term macrofossils it will be desirable to treat together many of the larger groups of invertebrates such as the Mollusca, Brachipoda, Echinodermata, Bryozoa, and Crustacea. Representatives of these groups often occur together, and abundantly in fossil form in most marine sedimentary rocks. Other groups of invertebrates are rarely found fossilized. In some, such as the Mollusca, minute species are often present, a study of which involves the use of the microscope, so that with these species there is an overlapping of the macro- and microfossils. However, for convenience, all forms more than 10 mm. in diameter will be treated as macrofossils. Most of the groups occur in rocks of all ages from the Cambrian to the Pleistocene. The general biological classification is based in large part upon living representatives. This classification is readily available in textbooks on zoölogy, paleontology, and historical geology and does not need to be repeated here except in outline; also, the broad classification of sedimentary rocks is readily accessible in textbooks on geology.

It is necessary especially to emphasize the collecting and recording of accurate locality and stratigraphic information for preservation with any fossils which may be obtained. It is much better to leave material in the field than to bring it to the laboratory without such information. The location should be recorded in a notebook or on labels, or both, in such detail that the original collector may be able to find the same place again himself or, from his description, another collector may be able to find it independently. Long experience has shown that the recording of locality information is a difficult matter and cannot be given too careful consideration. It is better to

indicate what appear to be trifling and inconsequential matters than to omit some point which would make a collecting station readily identifiable. Lost localities are legion. The experienced collector always endeavors to provide himself in advance with the best obtainable maps. Whenever possible, those which show Sections, Townships, and Ranges as well as topography should be consulted.

Besides keeping as accurate a record as possible of the exact location at which a collection of fossils is made, it is also important that the collector should note such stratigraphic data as he can obtain. Usually these consist of dip and strike of beds, nature and thickness of the fossiliferous zone, and the characters of bordering zones. It almost never happens that a single collection of fossils can be made through a thick series of sediments without violating the first principles of technique. Often, the chief use of fossils is the determination of stratigraphic sequence, and this obviously cannot be done if fossil zones are mixed.

Some large geological organizations have definite rules to govern the method of keeping the data for fossil collections. Sometimes it is insisted that all information be written down with ink, even in the field, because of the likelihood that pencil marks will rub and smudge. Many organizations that maintain a division of paleontology in connection with the geological department insist that the paleontologist shall completely ignore fossil collections which are submitted without detailed information on the locality and stratigraphy.

Since fossils occur in many types of sedimentary rocks, it will be convenient to treat the groups of macrofossils in accordance with the type of rock in which they are preserved. Five major groups may be recognized, corresponding with various degrees of alteration in the matrix rock.

Unaltered sediments.—These are usually rare and are most often found in the Pleistocene and Tertiary. Occasionally, however, localities may be found in the Mesozoic and even in the Paleozoic where very little modification of the minerals

has occurred. Such localities have become famous in paleontological literature and include the Silurian of Estonia, the Ordovician of the Arbuckle Mountains in Oklahoma, the Carboniferous of Spergen Hill, Ohio, the Cretaceous of Coon Creek, Tennessee, and the Eocene of Claiborne, Alabama. In these localities, there appears to have been very little or no disturbance of the sediments since they were deposited, and percolating ground waters have neither changed the mineral constituents nor deposited secondary minerals to any degree.

Fossils in such localities are usually beautifully preserved and except for loss of color are comparable in every way with the hard parts of living organisms of the same groups. Collections can be made with comparative ease, either by sorting out the material on the ground or by taking it to the laboratory in bulk. The latter method has much in its favor and is practiced on a large scale by some institutions. In much of the work done on the Gulf coastal plain of the United States and in the West Indies, the bulk material was shipped to the laboratories in barrels. Pits were usually dug into the formation in order to obtain fresh material and advantage was taken of such stream cuts and ocean cliffs as were available. Such a method of collecting provides an enormous amount of material for later study, so that figures computed with respect to relative abundance of species are quite important. Also, it is possible by this method to obtain series of specimens for the study of variation within specific groups, and, of course, a great many rare forms are thereby discovered. It is always necessary, however, to supplement this method of collecting by careful search of the outcrops for species which would not otherwise be obtained.

One objection which has been raised to the bulk method of collecting loose sediments containing fossils is that it is usually impossible to keep the associated parts of an individual together. Separate shells of bivalves get mixed and pieces broken from gastropods and other forms are often difficult to reassemble. It is just as desirable, in collecting in such soft

sediments, to use great care in assembling associated elements of a fossil, as it is where the rocks are harder and fossils are not so abundant or so easily obtained. For this purpose the field collector should have a supply of soft paper and cotton. It is also desirable to have boxes of a more or less rigid construction in which the fragile material may be packed separately. Often when it is not necessary to ship as much as a barrel of the bulk material, canvas bags may be used to advantage for the collections. The sand and silt will usually protect the fossils from breakage if the bags are packed in boxes for shipment.

Sometimes it is necessary to do some preparatory work in the field, particularly when the fossils are slightly leached or have been somewhat broken by compaction. It is desirable to take into the field adhesives such as shellac, cellulose cement, and possibly plaster of Paris. A small brush such as a toothbrush or a stiff paintbrush may be used in cleaning the specimens in preparation for putting the fragments together. By using such methods, it is often possible to save excellent fossils which otherwise would be completely lost. It may happen that such forms as *Inoceramus* and other large bivalves are broken into small rectangular fragments and, upon attempts to take them out, are broken again into innumerable smaller ones. Such specimens can usually be preserved, however, in the following manner. First, one entire surface should be carefully exposed. This should be covered with a thin sheet of paper, then with a piece of cloth or burlap, and this, in turn, with thin plaster of Paris. More layers of cloth and plaster may be applied until a rigid backing has been built up for the protection of the specimen. In other words, the technique of the vertebrate paleontologists is most desirable. By using their field methods, it is possible to save many remarkable specimens which otherwise would be lost.

The easiest method of preparing bulk material when it is received in the laboratory is to wash it through a series of screens with water. The coarser material is retained on screens

having a mesh of about ½-inch, and the finer part is successively graded downward until the final concentrate consists of Foraminifera with a few shells and perhaps sand grains. Methods of separation of the minute fossils are described in the treatment of Foraminifera. Greatest care in this as in other methods must be taken to prevent the mixing of collections through contamination of screens or otherwise, and as soon as the specimens are dry they should be kept in some sort of closed container until the time comes to sort and number them for permanent preservation.

Shales and soft sands.—Collecting fossils from shales and soft sands is often difficult because the specimens are poorly preserved and are chalky or fractured. Sometimes, indeed, the shells or other hard parts have been leached out completely by the action of percolating waters, and only the impressions are left. Frequently these can be collected and taken to the laboratory without injury, but often they disintegrate to such a degree that this is impractical.

Usually the best method of caring for such material in the field is by the use of plaster of Paris. A small quantity of this is easily carried. Sometimes it is better to treat the natural mold with an oil, dilute varnish, or cement in order to keep the material from adhering to the plaster after it has set, but specimens can usually be obtained merely by filling the mold with the wet plaster. In a short time thereafter the matrix can be broken away, and if the cast is carefully wrapped in soft paper or cotton it should reach the laboratory without the loss of much fine sculpture which may have been present. If plaster should not be available, but dilute cement or varnish can be obtained, the dry mold itself can be saturated and, after the adhesive has set, the specimen can be wrapped and transported safely. A point which is often overlooked by collectors is the failure to distinguish between external and internal molds. Usually the internal mold is much easier to collect than the external one, and as a consequence many of these reach paleontological laboratories. It is almost im-

possible to make identifications of value from such objects, whereas if the external mold is obtained much information may be got from it.

Gastropods, pelecypods, and other fossils are often present in soft sands and shales, the preservation being so imperfect that the shell is in a chalky condition. If an attempt is made to extract such a specimen, it will fall to powder and be irretrievable. But it is not difficult to obtain the material in perfect condition if care is taken in the field. A part of the technique worked out by the vertebrate paleontologists is necessary and is often repaid by success in the acquisition of specimens which are otherwise unobtainable. By the use of needles and small brushes, the specimen can usually be uncovered and one side exposed. If it is then painted with a dilute solution of "Bakelite" varnish or shellac and allowed to dry, the upper side will be well protected for extraction. Undercutting to remove it is a little more difficult, but if the fossil is an important one it should and can be done safely. The best method to follow is to remove the specimen with a part of the matrix adhering to the under side, then reverse it and dig away the sand or shale. What was originally the lower side is then painted in its turn.

When the specimens merely fracture into smaller or larger pieces, it is often sufficient merely to save the fragments and wrap them together in a package. If they are kept in this manner, it is not difficult in the laboratory to reassemble them in the proper form. When collections are made by an inexperienced person, small fragments are often ignored and discarded in the field. This is a mistake, because they help to fill in the contour of the specimen and obviate the necessity of patching holes with plaster. One of the best accounts we have seen of the care taken in removing invertebrate fossils is that of Sternberg (1932), in which he described the method of recovering a large *Inoceramus* more than three feet in diameter found in the Kansas Chalk. This specimen when found was fractured into many hundreds of small pieces not larger than

about one inch square. In spite of its condition he made an excellent museum exhibit of it.

Hard sandstone.—Making collections from hard sandstones requires tools of special size and weight to break and crack the matrix. Fossils may be present as impressions only, in which event the pieces should be saved for subsequent treatment and the making of casts. Sometimes the preservation may be poor and a more or less chalky condition may be present. The specimens are then very difficult to handle in the field, although at times it may be possible to preserve them with dilute adhesive. Often it is better to destroy the fossil completely and thereby expose the mold, from which casts are readily obtainable.

Sandstones are usually hard because of the deposition of secondary minerals in the pore spaces. The most common mineral thus found is calcite and this often accumulates in the form of nodules or concretions in an otherwise soft rock. Fossils are sometimes preserved in these hard masses and it is important that they should be extracted if possible. Under most favorable conditions, this can be done merely by breaking rock away from the object preserved. It may be, however, that the calcite has served as a cement, binding the matrix to the fossil so that the two cannot be severed; if so, there is no very satisfactory way to obtain the fossil in good condition. Sometimes by the use of small chisels it is possible to work it away from the rock, leaving the mold, from which a cast can be taken; but recrystallization may have taken place to such a degree that it is impossible to cause the rock and the fossil to separate. Sometimes the cement binding the sand grains together is of such a nature that excellent preparations can be made by means of heating with a concentrated flame such as that provided by an oxyacetylene blowpipe (Hanna, 1925).

Hard shales and slates.—Usually, but one method is available for the collection of fossils in these rocks. This merely consists of splitting the material into slabs along the bedding

planes, the pieces that show desirable fossils being saved and wrapped for shipment. Generally, such fossils are simply impressions, and these may have been pressed flat or otherwise distorted; therefore, in order to obtain as much information as possible, it is desirable to save both the upper and lower slabs, which contain the impressions desired. These can often be trimmed to some convenient size with the tools available in the field.

When the layers of rock are separated by a thin stratum of soft clay or decomposed shale or slate, it is desirable to saturate the fossils or impressions—whichever they may be—with dilute adhesive. Otherwise the most valuable parts of the specimen may be lost through rubbing with the packing material during transit.

Hard limestones.—Much of the collecting done in the Paleozoic and Mesozoic rocks is from hard limestones. Often the fossils have been weathered out more or less, and may even be found free around the base of an exposure. But again, the limestone may have disintegrated completely through weathering, so that the fossils can be obtained merely by washing out the resultant fine sediment.

Usually, however, the specimens are partly exposed on the surface of the limestone. The active agent in the weathering appears to be rain water containing a solution of carbon dioxide. Certain forms of calcium carbonate are known to be somewhat soluble in a water solution of carbon dioxide, whereas other forms are much less so. An attempt has been made to accentuate this property by enclosing the fossiliferous limestone in a steel cylinder with water and charging the same with carbon dioxide under a pressure of 100 pounds per square inch. The results obtained in a short experiment were not satisfactory, indicating that a large volume of water and a long period of time are prerequisites.

Special technique is rarely required for the extraction of fossils from hard limestones. The normal procedure is merely to crack the rock with a chipping hammer or some other suit-

able tool and to save the pieces wanted. In the field the usual care should be exercised either to stick pieces of the same individual together with adhesive or to wrap them in such a way that they will not become separated. Sometimes it is desirable to bring a substantial quantity of rock to the laboratory and there work upon it with tools which are not ordinarily available in the field. Beautiful preparations can sometimes be obtained by the use of small chisels, needles, and awls. Some limestones will crack away from fossils under the judicious use of a fine-pointed flame; this is particularly valuable in exposing the umbilicus of cephalopods. Also it has been found that the rock may profitably be heated in a mass to no more than a dull red. Upon its then being plunged into water for cooling, disintegration and cracking will take place, resulting at times in the loosening of fossils which would otherwise adhere tenaciously to the matrix. Buckman (1911–1912) has described a method of heating fossiliferous rocks with flames of various kinds in order to expose the muscle scars and other markings on the interior of brachiopod shells.

Bernard (1894) describes the use of the sand blast in the preparation of trilobites; and Böse and Vigier (1907) give methods of applying hydroxides.

Although invertebrate fossils are usually preserved as some form of calcium carbonate, there are records of its having been replaced by some other mineral. Chalcedony is probably the commonest of the replacing substances, but fossils preserved as a phosphate, pyrite, or strontianite are occasionally found. In Australia there is a locality where the original calcite of shells has been replaced by beautiful fire opal. Also, there are records of fossils found in other types of rocks, but these are comparatively rare. It sometimes happens that shells and other invertebrates have been picked up in lava flows and floods of volcanic muds or ashes, and there are accounts of recoverable fossils found in schists, more or less highly metamorphosed.

Tools and Equipment

The field geologist is most often provided with no other tools than a simple prospector's pick, a Brunton compass, notebook, pencils, and articles necessary for keeping his records. The feats performed by an experienced person in the extracting and preparation of fossils with so simple a hammer are really astonishing. But, because only a limited amount of excavation and rock breaking can be done with the implement, additional tools should be provided whenever possible.

For collecting material found in loose sands and silts, a shovel and large-mesh screens are necessary, and it may sometimes be desirable to sink pits in order to get better-preserved specimens. A large-sized pick is often a desirable tool, particularly when a mass of rather firm rock or shale must be handled. A long-handled sledge weighing from 8 to 12 pounds is very useful when collecting is to be done in hard rocks. It is available in many different shapes, and the individual collector will generally prefer the form to which he has become accustomed.

In almost any type of collecting, except in loose sands, a small chisel and a small, square-pointed piece of steel are extremely useful. The steel need not be more than ½-inch thick, and therefore these articles do not add materially to the weight of the field man's kit. These tools, with the prospector's pick, will aid the collector in the extraction of many specimens, and in the trimming away of the matrix rock will lessen the danger to the fossil itself.

Quarries have rarely been opened for the sole purpose of collecting invertebrate fossils, as has been done for vertebrates. However, as time goes on and the need for more refined determinations of paleontologic facts becomes apparent, it is probable that such work will be undertaken. The machinery and equipment chosen for each particular job will, of course, be determined by conditions at the time.

Often, trips to favorable collecting localities are made by

parties of students. It should not then be difficult to provide all the necessary equipment for the preservation of the material collected in the best possible condition. Excavating tools, plaster of Paris, and some form of adhesive are of first importance. A liberal supply of packing material should also be provided, so that the specimens collected will not be marred or demolished in transit to the laboratory. If the locality requires an appreciable amount of work in hard rock, a liberal supply of sledges, steel splitting wedges, and sometimes rock drills should be provided. It will be found profitable in many places to employ explosives for the exposure of fresh material.

The equipment required for the preparation of vertebrate material after it reaches the laboratory is generally sufficient for most of the work required in connection with invertebrates. There is almost no limit to the possible purchase of machinery and tools. Only the most essential items will be mentioned here.

An oven of some sort, preferably one with thermostatic control of heat, is very desirable. This should be chosen so that temperatures as high as 150° centigrade may be maintained for several hours. The oven is especially useful for the drying of specimens and plaster casts, and the polymerizing of adhesives used on them. It will be found useful also in the preparation of microscopic material, as mentioned on a later page.

A blast lamp or some sort of muffle furnace is advantageous when bulk material needs to be heated for disintegration. An oxyacetylene outfit will also be found convenient. Many matrix rocks when heated with this flame spall off in small flakes at a rapid rate, thus permitting the exposure of more or less fragile specimens that would not stand the impact of hammer and chisel. Rocks particularly adapted to this type of operation are those which contain a rather large amount of hydrated clay minerals. Owing to the excessive heat of the flame, the escape of the water is so rapid as to be almost explosive.

The paleontological laboratory usually becomes provided after a time with a variety of chemicals and reagents. Some of these are in almost daily use; others are needed but rarely. The use of ordinary liquid glue can only be tolerated when there is no other adhesive available, but it is far inferior in permanence to such cements as cellulose nitrate or acetate. The hardening of soft chalky sediments and plaster of Paris casts was formerly accomplished by the use of diluted shellac in alcohol, but there are materials now available which are preferable to these.

The most valuable of all is a dilute solution of "Bakelite" varnish. The specimen is painted with this material or dipped in a bath of it, after which it is heated for an hour or more at a temperature of around 150° C. The process has been described in detail by Swinton (1933), but it is so valuable that the essential aspects deserve repetition. The varnish found most suitable for the purpose is known as "Bakelite Varnish B.V. 1112" and is available at reasonable cost. The solvent and thinner is most conveniently procured from the manufacturer or sales agent. The resin tends to polymerize and become thicker and more viscous at room temperatures, and therefore it is not advisable to provide too large a supply at one time. It is desirable to mix some of the material with thinner in a separate container, making a quantity sufficient to permit the immersion of the specimens to be treated. These, of course, must be thoroughly dry at the time. After immersion, they are allowed to drain on a screen or some other support until the surface is free of excess, after which, if there is any perceptible gloss, they should be wiped off with a cloth moistened with solvent. In this form the specimens will last indefinitely. If, however, they are complete and are desired for permanent preservation in a collection, they should be subjected to the oven treatment indicated above. After polymerization at a temperature of 150° C, the varnish becomes insoluble and infusible.

In the absence of a thermostatically controlled oven, other

heating appliances may be utilized if proper care is taken to avoid excessive or too little heat. It should be remembered, of course, that the solvents and thinners of such varnishes are inflammable and precautions should be taken accordingly.

"Bakelite" varnish diluted with solvent is an excellent substance to use in the field for the handling of friable and chalky specimens, in place of the cellulose cements and shellac.

Almost all the chemicals needed in the preparation of invertebrate fossils are also useful in the preparation of the microscopic forms treated below; hence reference is made to that section for an account of them.

One of the most generally useful things in a paleontological laboratory is modeling clay. For a temporary support to hold articles in a definite position it is unrivaled. When a fossil has to be reassembled from fragments, it is often convenient to use a sheet of clay for backing; upon completion, the interstices and cavities left by missing parts can be filled with plaster. Clay is also very useful for making molds of fossils. The procedure in the California Academy of Sciences is to roll out a sheet of clay large enough to envelop one-half of the specimen. The surface is dusted with talcum powder and then pressed firmly upon the part of the object to be reproduced. Overhangs and distortion of the mold should be avoided. Plaster is poured into the cavity and allowed to set. Usually, before it has completely hardened it is removed from the mold and the block is trimmed to a size suitable for a standard tray. In this method of casting, two or more impressions must be made in order to reproduce the form of most invertebrate fossils, but the task is so easily and quickly done that it has become standard practice.

Microfossils

Under this heading it will be convenient to group all the small animals that have skeletal parts suitable for preservation in sediments. The division point between so-called macrofossils and microfossils is an arbitrary one, but a line can usually

be drawn between the two at about 10 mm. Thus among the microfossils there will fall many small forms of the groups treated in the preceding section, as, for example, Mollusca, Bryozoa, and corals. The division is made primarily because in the study of the microfossils a considerable degree of magnification is required. This, of course, is also true of certain macrofossils, particularly in the study of fine structure on polished surfaces or in thin sections.

The use of microfossils for the determination of the relative geologic ages of rocks has been attempted in a more or less cursory manner in the past, but it is only since about 1922 that the work has been developed on a large scale. This has resulted from the need of exact correlation data in the drilling of oil wells and from the need of suitable tools for getting core samples at any desired depth in the well. The core samples are cylindrical and are usually not more than three or four inches in diameter—so small that few macrofossils can be obtained from them, and, usually, definite correlations would be impossible from a study of those recovered. Microfossils, however, are often abundant in them and have been found to be trustworthy indicators of geologic age. It is often possible to extract many thousands of perfect specimens of small fossils from a handful of material, whereas to concentrate the same number of macrofossils from the same formation would require the handling of several hundreds of tons.

The number of individual microforms in a very limited amount of sediment is often so great as to be almost inconceivable. Miller (1889) quoted Leidy as having found 18,700 tests of Foraminifera in an ounce of mud at Atlantic City, New Jersey, and 38,400 from a similar amount at Cape May, and he estimated 280,000 from the same quantity at Newport, Rhode Island. The number of smaller forms is beyond the power of human comprehension. A cubic millimeter of diatomite will contain a thousand individual fossils, yet this organic sediment in California alone can be measured in cubic miles.

As a consequence of the importance of microfossils, paleontological laboratories have been developed within the geological departments of most of the oil companies of the world. Some of these are large and employ many persons. Their interests have been more or less in common and there has resulted the formation of a society banding them together—the Society of Economic Paleontologists and Mineralogists, a division of the American Association of Petroleum Geologists. In March, 1935, the society had 275 members. It publishes the *Journal of Paleontology*, and in 1935 arrangements were made for the joint publication of the *Journal* by this Society and the Paleontological Society, an affiliate of the Geological Society of America. Thus the paleontological activities of the United States have been combined in one journal, now in its eleventh volume. Much of the matter thus far published in this serial has dealt with microfossils of various groups.

The groups of animals usually considered to belong with the microfossils are Foraminifera, Ostracoda, Bryozoa, and Mollusca among the calcareous forms, and Radiolaria and sponges among the siliceous forms. These divisions are not very definite, since there are calcareous sponges and siliceous Foraminifera, and Foraminifera built up of extraneous material bonded with either calcareous or siliceous cement. It is also convenient to group under the microfossils certain small plants which have skeletons suitable for preservation in sediments. These are the *Diatomaceae, Silicoflagellata,* and *Archaeomonadaceae.*

Two other groups of objects, coccoliths and rhabdoliths, are often found in marine sediments and occasionally are fossilized. They appear to be fragments of minute pelagic calcareous Algae and, when complete, are referred to as "coccospheres" and "rhabdospheres" (Murray and Renard, 1891). They do not appear to have been used to any appreciable degree in geologic correlation. They are very small in size and are usually mounted on glass slides in a transparent

medium for examination by transmitted light. There is also a group of more complex plants, the Charophyta, of which the modern *Chara* is a representative. The oögonia ("seeds") developed by members of the group are small, ovate, calcareous objects, often having spiral markings. These have been found abundantly in sediments ranging in age from Pennsylvanian to Recent and some little study has been given to them. One branch of the group, the "trochiliscids," is found in marine sediments of lower Mississippian and Devonian age (Peck, 1934).

Calcareous Algae (*Lithothamnion,* etc.) are important builders of limestones, and the fossil forms have been studied and used widely. Usually the characters are determined from a microscopic examination of a polished surface.

The types of sediments in which microfossils are found vary endlessly from unmodified and loose sands, silts, and clays to thoroughly metamorphosed, schistose rocks. Sometimes all the fossiliferous rocks that will not disintegrate by any of the ordinary laboratory procedures are studied in thin section, the technique of preparation being similar to that in petrography and microscopic crystallography.

It is also possible to determine the essential characters of the fossils contained in the rocks by an examination of the exposed surfaces. Much thought has been given to the disintegration of hard limestones, siltstones, and cherty shales, but no very satisfactory means has yet been found. In some silty and calcareous rocks the binding cement can be destroyed by strong mineral acids, after which, through proper screening and washing, the fossils that are preserved as silica can be recovered.

Various forms of replacement occur with the microfossils even more commonly than with the macrofossils; thus it often happens that the original calcite, of Foraminifera for instance, has been removed and the cavities filled with solid calcite or silica or, in rare occurrences, pyrite. In some of the more siliceous shales and ashy silts, the siliceous organisms

have been dissolved away and the cavities filled with calcite, silica, or pyrite. Only the impressions may be left. No very satisfactory method seems to have been developed for the making of casts from these impressions, because it is difficult to find a medium which will reproduce the fine sculpture usually found. Sealing wax, gutta-percha, and plaster of Paris have been tried with indifferent success. Various metals have also been experimented with, both by melting them and by electroplating. Although the resultant casts have been better than nothing and have often been useful, they have always been a poor substitute for the fossils themselves. Perhaps if some method should be attempted which would employ the casting material under pressure, better preparations would be obtained. Equipment for similar processes is used in industry in the making of die castings, printer's type, and so forth, but apparently it has not as yet been adapted to the work with fossils.

Foraminifera and Ostracoda.—Economically, the most important group of the microfossils is the Foraminifera, and a large literature has been built up around it. It is primarily for the study of this group that many of the oil companies have established special laboratories. Because methods of collecting and extracting Ostracoda and Foraminifera are almost the same, it will be convenient to treat the two groups together. Many other small objects are often recovered by the same processes and usually are prepared at the same time.

Bulk samples are of two kinds, those collected from surface exposures and those obtained from wells. It is important that both kinds should be preserved in such a manner that danger of contamination is reduced to a minimum. The usual procedure is to enclose the material in envelopes such as are supplied for ore samples and seeds. These have a metal clasp across the top with two ends projecting; when the sample is enclosed, the end is rolled down and the two projecting metal tips are bent over for secure sealing. Other styles of envelopes are often used, depending upon the kind of sample and the con-

ditions under which it is to be transported and stored. Most of the envelope manufacturers will supply containers fastened with waterproof adhesive, if requested; these are highly desirable if the samples to be enclosed are moist. All the usual precautions must be taken for the recording of essential data. It often happens that several hundred samples will be taken from one set of well cores and a particular laboratory will be concerned with the study of numerous sets at the same time; contamination would most certainly occur if careless methods were followed.

Drying is the first essential in the preparation of a sample for study. This can be done in an evaporating dish over a flame, or the specimen may be allowed to dry out naturally at room temperature. Many laboratories, however, have ovens in which the specimen can be placed and maintained at a specified temperature. After drying, it is crushed so that the individual pieces are rather small, that is, 3 to 10 mm. in greatest dimension. Crushing may be done slowly and rather imperfectly with a hammer on a piece of steel, or a mortar and pestle may be used if care is taken not to grind the material. In order to hasten the work, several forms of rapid crushers have been devised for use on a laboratory scale. Probably the one most widely used is that originally constructed by Mr. H. L. Driver, of the Standard Oil Company's Los Angeles laboratory. This consists of a pair of rolls (fig. 43) about 6 or 8 inches in diameter, usually constructed of oil-well drill pipe. Ends are welded in, and shafts are extended through the middle of each. These are set in bearings in channel irons with the ends projecting so that a handle about 2 feet long may be attached to one end of one roll. To the other ends of both rolls are attached two coarse-toothed gears about 6 inches in diameter. Means are provided either by set screws or by an eccentric to vary the distance between the two rolls. The apparatus is extremely efficient and rapid in operation, is easily cleaned, and affords little chance of contaminating samples if reasonable care is taken in its use.

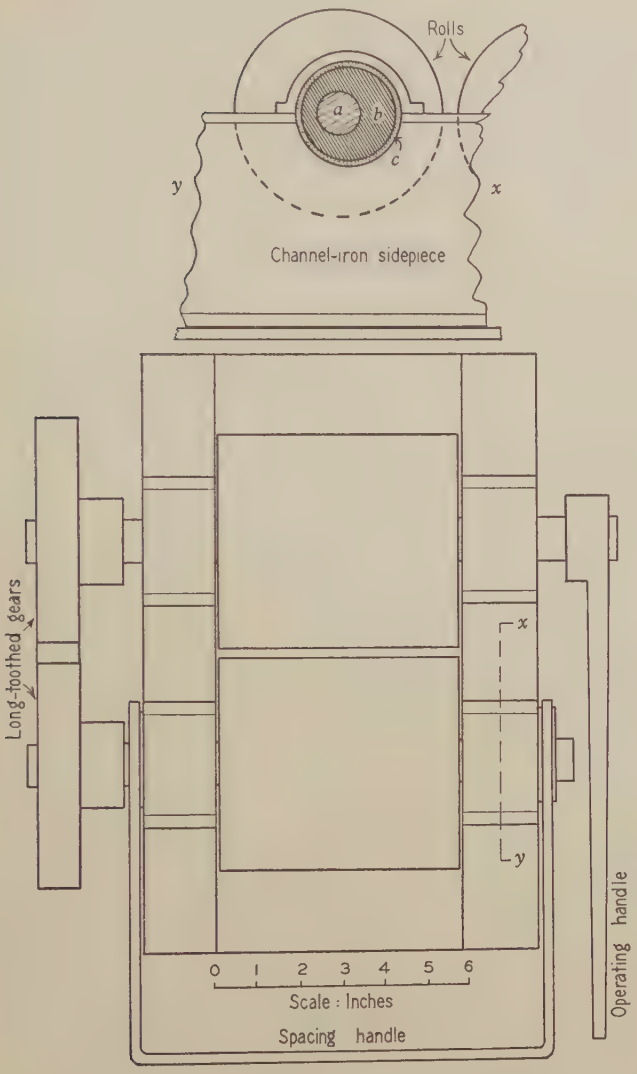


Fig. 43. Crusher rolls for breaking shales preparatory to disintegration. Details: *a*, roller shaft; *b*, eccentric bushing, fastened to spacing handle; *c*, bushing in sidepiece.

After the sample is crushed, the treatment it receives depends upon various factors, the particular procedure used being in large part dependent upon the experience of the operators. Sometimes nothing further needs to be done, an examination of the surface of the specimen with hand lens and binocular microscope sufficing to reveal forms that are diagnostic enough. Thus, after long experience in a particular district, a paleontologist is often able to determine zones from the Foraminifera observed in a sample with a hand lens in the field.

When the necessary familiarity has been gained, the crushing of the sample may of course be omitted, as well as all subsequent treatment. However, if it is to go through the various processes of concentration, it must normally be moistened after the crushing. If the sample contains clay minerals, these will often take up water to such a degree that the shale will disintegrate when immersed. If so, it may be put through the usual screening processes at once. More often, however, some preliminary treatment or agitation is necessary. Boiling in water is usually beneficial and hastens the disintegration. The use of a pressure cooker giving pressures up to 10 or 15 pounds of steam is even better, with many types of shales. Various stirring devices have been adapted for use at this point in order to complete the disintegration of the shale particles. One of them, which has been used for many years, was constructed along the pattern of an ordinary egg beater except that heavier materials and a single shaft were used. Brass strips about $\frac{1}{16}$-inch in thickness were bent around in circles from the end of the shaft and soldered, thus forming a circular stirrer (fig. 44). This is attached to a chuck on a motor shaft, a small drill press, or other form of propelling apparatus. The tool works rapidly and efficiently on many of the softer shales, but has no crushing action and is therefore not satisfactory for firmer materials.

One of the most useful disintegrators which has been devised is a trunion type of roller mill (fig. 45). In this machine

a series of three or five rubber-covered rollers, each about 2 inches in diameter, and their surfaces held from 1 to 1½ inches apart, is arranged in a horizontal plane. Roller or ball bearings may be provided for the shafts, if desired. One of them is driven by a motor, either directly connected through a gear-reduction box, or with a belt, so that the revolutions obtained are about 150 to 200 a minute. The material to be disintegrated is put in a round glass jar about 3 inches in diameter and 4 to 6 inches long, the cover being of the usual screw type used for the packing of food products. A heavy roller is introduced into the jar with the material. Many types of roller have been tried. One of the common ones is a cylinder of brass with longitudinal and concentric grooves cut upon it, thus producing on the surface a series of rows of pyramids about ⅛-inch square. The ends of this crusher are covered with soft rubber protectors, the thickness of which is such that the points of the pyramids of the metal do not quite come in contact with the inside surface of the glass container. Thus assembled, the glass jar is placed upon the trunion and allowed to rotate long enough to produce thorough disintegration. A large number of samples can be treated in it at the same time and the results are generally very satisfactory. Unfortunately, because the equipment is not available on the market each laboratory must have its own constructed. The apparatus is simple and relatively inexpensive and if made with properly protected bearings it will last for years.

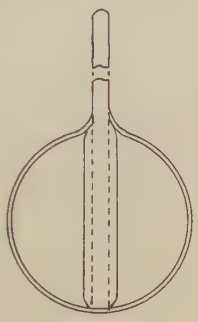


Fig. 44
A simple type of agitator.

Various types of miniature mill have been devised and some of them have given satisfactory results. One of these, invented by Mr. H. L. Driver, is a horizontal, revolving brass disk somewhat concave on the upper side. A rubber roller with horizontal axis travels in the concavity, and the pressure

between the two can be varied with a screw. The material to be disintegrated is placed in the mill and the revolution of the machine causes it to be thoroughly crushed and disintegrated. An annular jet of water is provided, with force just sufficient to wash away the finer material into a screen placed underneath a large hole in the center of the revolving plate.

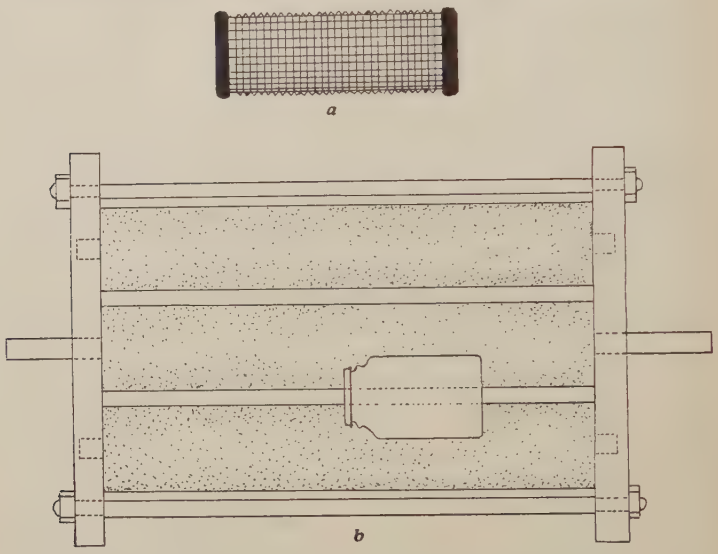


Fig. 45. Trunion type of roller mill used for the disintegration of shales. Form of brass roll used inside jars is shown at *a*.

Among other types of mill used, one employs a stationary vessel, sometimes made of rubber and sometimes of glass or metal. The rollers are fastened on the two ends of a horizontal axis and this, in turn, is attached to a vertical axis which can be made to revolve slowly with any one of several forms of mechanism.

In the absence of any of these types of machine, disintegration can often be effected merely by the use of the fingers and the palm of the hand. This is an efficient method, because the fossils do not come in contact with any hard substances and

are not likely to be injured or crushed. Sometimes it is convenient to put the material in a rubber mortar, and the disintegration is effected there by the use of fingers or rubber pestle.

Sodium hydroxide and other chemicals have been employed to aid in the disintegration of some types of shale. A strong solution of this material is an effective solvent for silica and many of the silicates; for this reason metal beakers such as copper or iron ones are preferable to glass, although the latter is widely used. In some laboratories a definite concentration of sodium hydroxide has been found desirable, and equipment has been provided for the rapid boiling of samples in the solution. A large number of samples can be treated at one time, depending upon the size of the heating appliance, which may be a hot plate, gas plate, or a jacketed steam-heated plate. A reflux condenser suitable for keeping the concentration of the solution constant, suggested by Mr. Kenneth E. Lohman, of the United States Geological Survey, has been adopted by D. D. Hughes and Boris Laiming, of the Texas Company, Los Angeles. In this a small Florence flask which will pass into the beaker without much wall clearance is employed (fig. 46). Cold water is made to circulate through the flask, thus acting as an effective condenser for the vapors given off by the boiling solution. Any other style of reflux condenser will, of course, be satisfactory, providing the container holding the sample is adapted to it. The process is especially valuable when the matrix is tough and tenacious and the fossils delicate and easily crushed. Repeated freezing and thawing of some shales will cause disintegration in a very effective manner. Usually the process does not need to be performed more than two or three times (Hanna and Church, 1928).

In the past, the force of crystallization has been employed in the disintegration of various types of rocks, but the process fails so often that it has been abandoned by most laboratories. One method of employing it is to place the dry and crushed

shale fragments in an evaporating dish with about an equal quantity of some kind of salt which has a very high percentage of water of crystallization, as, for example, sodium acetate. Upon application of heat the salt will dissolve in its water of crystallization and will saturate the fragments of shale. Upon cooling, a solid mass will set. The melting and solidification can be repeated several times, and when it has proceeded long enough the salt may be readily dissolved in a fresh supply of water.

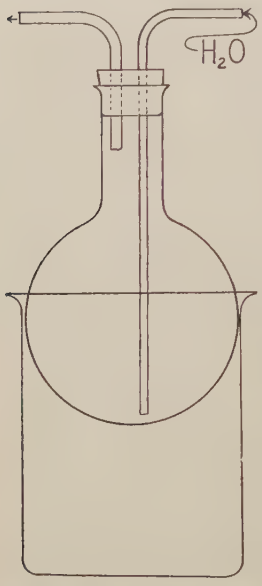


Fig. 46. Reflux condenser.

After completion of any of the methods of disintegration, it is necessary to pass the material over screens. Those in most common use for Foraminifera are 20 and 100 mesh. A coarser screen of about 10 mesh is desirable for the removal of pebbles and large fragments. It is often desirable to use a screen of 150 mesh in order to collect the smaller fossils. It is customary in most laboratories to use brass screens 6, 8, or 10 inches in diameter, with the junction between the wire and the wall filled with solder. This procedure lessens the danger of contamination from one sample to another.

Quite a bit of practice is necessary in the efficient use of screens and much dexterity has been acquired by some paleontologists. Upon completion of the disintegration of the sample, the resulting mud tends to clog the meshes of the screen, and it has been found that a jet of water under intense pressure aids effectively in keeping the openings free. Also, shaking the screen in a horizontal plane at a rate of about 60 shakes per minute is a decided benefit and aids further in the disintegration of the shale particles yet remaining.

This treatment is sometimes too vigorous for delicate forms or for those not too well preserved, and in preparing these one may resort to simple decantation or to the use of a siphon with a minimum amount of agitation. So great a degree of care is usually unnecessary, but will sometimes provide a collection which would otherwise be unobtainable.

The material that comes from the screens, washed in the manner indicated, is clean, free from adhering particles, and ready for drying and permanent preservation. The drying may be done in an evaporating dish, either over a flame or in an oven, or sometimes a filter paper may be used. Occasionally, particles of shale are retained on the screen with the fossils, and in the drying process these tend to disintegrate further and cover the specimens with a fine sediment. It is then necessary to repeat the washing process on the screen.

It is very important that a screen be thoroughly cleaned after it has been used for a particular sample. Many Foraminifera tend to wedge themselves in the wire meshes. Most of them can usually be dislodged by the use of a wire brush made in the style of a shaving brush. In order to be more certain that all calcareous forms have been removed, dilute hydrochloric acid may be used; this will attack the screen to a slight degree but not enough to cause much injury. Monel metal is highly resistant to some of the mineral acids and therefore makes satisfactory screens.

In order to eliminate some of the handwork in the operation of screens, various shaking devices have been tried, but thus far they have not proved entirely satisfactory. Mechanical shakers in which a series of closed jars may be placed are in use in some laboratories. When this machine is set in operation, the disintegration is carried on by the rubbing of the shale particles against one another. This method is much slower, as a rule, than the one in which a mechanical stirrer or some type of mill is used.

It often happens that when the crushed samples will disintegrate without being boiled in water or some solution many

of the Foraminifera will float on the surface, owing to the action of enclosed bubbles of air. Boiling will effectually displace this air so that the tests will sink. If it is desirable, however, to recover the floating forms, this is effected easily by pouring the liquid containing them into a filter funnel. Pure concentrates of beautifully preserved material can often be obtained in this manner. The procedure is frequently used with living material found in ocean-bottom samples.

A modification of the process used in the extraction of siliceous fossils has been recommended by Secrist (1934) for the recovery of arenaceous Foraminifera from Paleozoic limestones. Small fragments of the rock are treated with a 50 per cent solution of hydrochloric acid, to remove the calcite and other soluble materials. The residue is carefully washed but not screened. Throughout the process extreme care must be used to prevent the disintegration of the tests of the organisms; otherwise the procedure is similar to that usually employed in the recovery of insoluble residues from limestones.

After the fossil material has been concentrated as well as possible by means of disintegration and the use of screens, some workers prefer to pick out the representatives of various species while these are still immersed in water. This is done by putting the concentration in some sort of petri dish or other shallow vessel, usually provided with a blackened bottom and placed under a binocular microscope. Small brushes, such as No. 00 camel's hair water-color brushes, are used for the purpose of picking out the specimens. The selections made are assembled on blotting paper or some other surface for drying and are then transferred to permanent slides for preservation.

Other operators prefer to dry the cleaned material and make the selections from a thin layer spread out on a shallow black-bottomed tray. An excellent tray for this purpose can be made of wood or plaster of Paris shaped as shown in figure 47. The surface of the projecting shelf is made lower than the squared bottom of the tray, the difference being the thickness

of the bottom paper of the slide. In use the slide rests on this shelf, and since the bottom of the tray and the bottom of the slide are in the same plane they will be in focus when shifted on the stage of the microscope. Objects selected out of the tray can thus be shifted to the slide by moving the appliance on the stage, and it is not necessary for the microscopist to remove his eyes from the oculars during the work of picking out the fossils. A drop of gum-tragacanth solution for moistening the brush is put at some convenient place in the tray. If the bottom of the tray be dead black, ruled into squares with white lines and these numbered in white, the microscopist can search the entire surface without going over any part of it more than once.

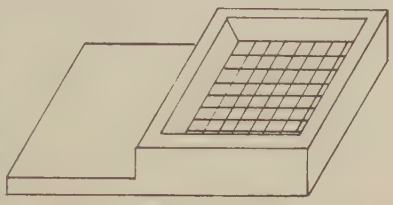


Fig. 47. A useful tray for picking out Foraminifera.

The actual picking up of the specimens under the microscope may be performed with a slightly moistened brush, or a dissecting needle or other sharp-pointed instrument. Dry specimens are usually placed immediately in the slides for permanent preservation, although at times it is convenient to gather them in a group from which further selecting may be done. Species may be arranged in a predetermined order and the specimens may be selected in any way to suit the fancy of the student at the time.

Even when the best possible technique is used in the cleaning and screening processes, it often happens that the fossil content of the concentrate will form a very small part of the total. For instance, when the sample consists essentially of loose sand composed of grains of approximately the same size as the tests of Foraminifera, the grains will concentrate along with the fossils. In other samples, shales will break down into a series of small flakes approximately the size of the fossils and will refuse to disintegrate further. Various methods have

been employed for separating the fossils from the bulk material, the most common of which is by the use of bromoform. The difference in specific gravity between calcite and silica or feldspar is such that if the density of the liquid is properly adjusted the sand will float and the calcite will sink. When the Foraminifera are preserved as solid calcite, this procedure is effective. If, however, the tests are empty the bromoform will not penetrate the chambers completely and the fossils will float along with the sand grains. It is then desirable to reduce the density of the bromoform so that the sand will sink and leave the fossils floating. Carbon tetrachloride has been found valuable for this purpose, and there are probably many other organic liquids that would serve equally well. It is essential that the liquid shall not penetrate the pores of the tests.

The separations are usually made by the use of standard separatory funnels (fig. 48). Alcohol may be used for diluting the bromoform to reduce the density, and when it is desired to reconcentrate the liquid the addition of water will remove most of the alcohol. A laboratory still is occasionally resorted to in the making of rectifications. Instead of a separatory funnel, an ordinary glass funnel is sometimes employed; this is provided with a stopcock welded onto the stem or attached by a rubber connection.

Recent experiments with flotation technique indicate that it is sometimes possible to separate Foraminifera from other material by this means. The laboratory of the Bataafsche Petroleum Corporation (1935) has recently published an account of a method which it has found satisfactory: the disintegrated and screened sample was treated with hot pyridine to remove any oil or grease, then stirred for a time in water to which a small amount of soap had been added, and when a stream of air was blown into the solution a foam was formed and most of the Foraminifera floated off the top with this.

There are almost as many methods of handling the cleaned material for permanent storage and study as there are labo-

ratories and workers. Each worker must devise the system best adapted to the organization in which he finds himself a unit. There are certain aspects in common, however, which may be outlined for the present purpose.

Many different slides have been devised for the permanent preservation of Foraminifera and other small fossils. These usually combine a cell of some sort with a cover for it. Strips of wood, metal, and glass have been hollowed out with cavities of various shapes and sizes. Most of them have been made in the dimensions of the standard microscope slide, 1 by 3 inches. Mollusca are usually preserved in large collections in small shell vials, the size depending upon the standards of length and width of the cardboard trays in use.

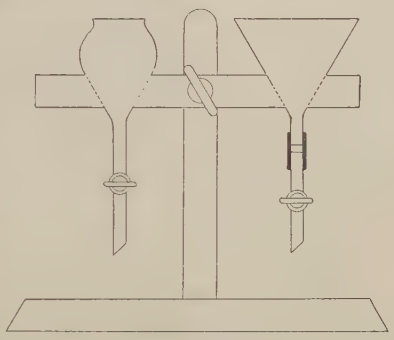


Fig. 48. Funnels for separation of fossils by means of heavy liquid.

One type of slide that has gained wide use is illustrated in figure 49. It has a standard microscope slide for a cover, a thin cardboard strip for a bottom, and a sliding member between. The assembly is bound together with a strip of gummed "kraft" paper which folds over the edges of the glass and is fastened there. The sliding member is composed of two strips of cardboard measuring 1 by 3 inches, glued together, the lower one black, the upper one white. The upper one is perforated before assembly with one or more holes of variable size up to half an inch in diameter. The holes are best made with a hollow steel drill such as factories use for perforating large quantities of paper; a punched hole is usually somewhat ragged. This slide is rigid, yet permits the fossils to be studied without removal. It is somewhat expensive to manufacture and is too thick to fit into the standard microscope slide box. Most workers file them in envelopes in standard cabinets.

Many paleontologists use a slide which is essentially the removable member of the one just described. The black cardboard is used for the base, to provide a black background upon which to mount the fossils. When this cardboard strip is used alone, some sort of cover should be provided for the cell; a square cover glass is sometimes used for the purpose, but a piece of celluloid, as, for example, a heavy photographic

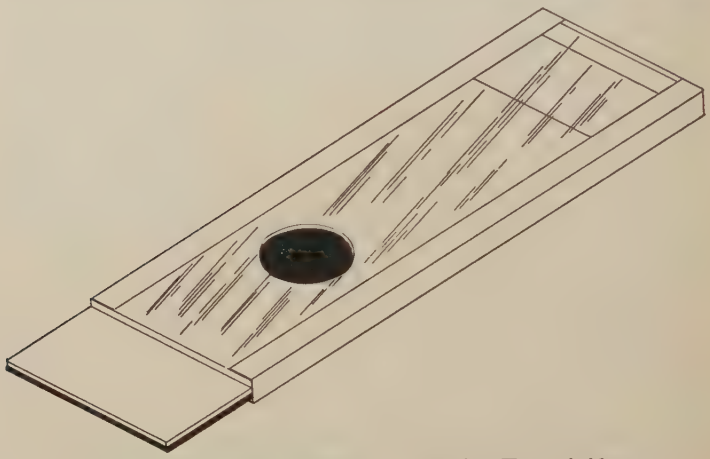


Fig. 49. A form of slide used for mounting Foraminifera and other small fossils.

film, is better. Guides are provided to hold the cover in place, as all cardboard strips are somewhat flexible. The bottom of the slide may be made of heavy photographic paper upon which have been printed minute squares or circles, with numbers, the lines being white on a black background; such slides are extremely beautiful when well made and are comparable to some which have been made of molded wax (fig. 50).

Franke has given much attention to the preparation of Foraminifera and other small fossils, and his papers (1922*a*, *b;* 1928; 1930; and 1935) are worth careful study. He has given special attention to slides and cabinets, some of which are illustrated in figure 51.

Others who have lately written upon technique are Feifel

(1930), Alexander (1933), Hecht (1933 and 1934*a*, *b*), and Scheffen (1934). The student who wishes to investigate their methods will find the citations in the bibliography below.

Various types of adhesive have been employed to stick the fossils to the bottom of the cell. A dilute solution of gum tragacanth is in common use, although gum arabic and even gelatin are satisfactory. It is essential that the solution of adhesive be made dilute so that when the gum evaporates there will be no noticeable amount remaining on the specimen.

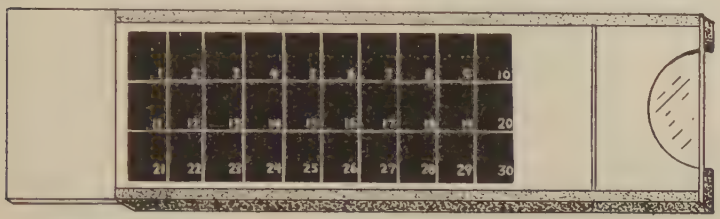


Fig. 50. Foraminiferal slide used by Dr. Joseph A. Cushman.

The washed bulk material is often retained for future study, and different methods have been adopted for the preservation of it. One common storage container in general use is a small glass vial with a screw top. Small envelopes are used in many laboratories. When the number of samples is large, as it often is, various methods of systematic filing have been adopted.

The microscope in general use for the study of Foraminifera and fossils of comparable size is commonly called a "binocular"; though this is really a misnomer, because there are other types of microscope which are as much binocular as this one. The low-power instrument referred to, however, is a double microscope with paired objectives as well as paired oculars. It is often referred to as the "Greenough type." Most of the optical companies manufacture it, and it gives satisfactory service through many years of constant use. A very desirable feature is the provision of prisms for erecting the image so that manual work under it requires no special effort or prac-

tice. Lenses are usually selected to give magnifications ranging from 10 to 15 to somewhere near 100. Other than careful cleaning of the lenses, the only adjustment likely to be required in this instrument is the bringing of the objectives back into position so that the images formed by the two sepa-

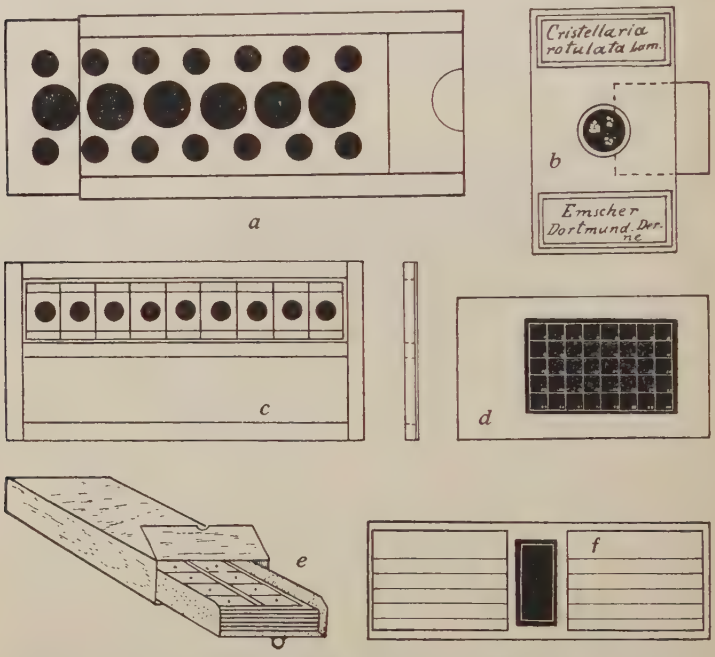


Fig. 51. *a*, *b*, *d*, *f*, types of slides for Foraminifera as illustrated by Franke (1935); *c*, slide holder; and *e*, cabinet, after Franke (1935).

rate microscopes will coincide. Sometimes the objectives get displaced and vision through them is then greatly impaired. Each objective is usually provided with three centering screws. If a card with a series of concentric circles and cross lines at right angles (fig. 52*a*) be constructed and used as the object, it is very easy to ascertain if the two images coincide. If they do not, one tube should be focused upon the centered circles, and it will then be comparatively easy to adjust the

centering screws of the other objective so that its image is likewise central (Hanna, 1931*b*).

A better field consists of a few concentric circles with three radii drawn 120 degrees apart, on a strip of smooth brass or aluminum (fig. 52*b*). This object is adjusted on the stage so that the three radiating lines point outward from the axis of the objective to be adjusted, in the direction of the three screws. This makes it easier to determine which ones to loosen and which to tighten. In order to make the field of view move toward one screw, this screw must be tightened. With a little practice any pair of objectives can be adjusted in five to ten minutes so that the fields of view will be approximately coincident. A more exact adjustment can be made by providing two circular disks of thin metal which fit closely inside the oculars and rest upon the diaphragm (fig. 52*c*). In the exact center of each disk there should be a small hole 1 or 2 millimeters in diameter. These stops will narrow the field of view greatly and will permit a much closer approximation to precise coincidence. The fibers of a piece of paper are small enough to use for guides, but a better test object is the central indentation on the metal plate (fig. 52*b*) made by the compass in drawing the circles. If the two images of this point can be made to coincide exactly through a 1-mm. aperture in the ocular, the user of the instrument can be assured that the objective is in excellent adjustment.

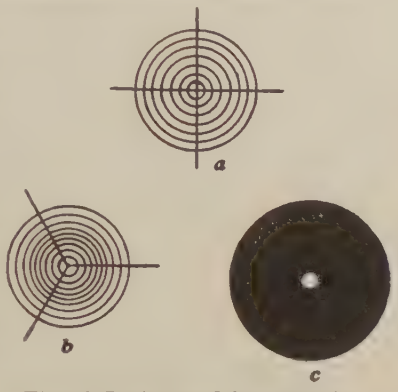


Fig. 52. Design used for correcting binocular microscopes.

There is no thoroughly satisfactory illuminating apparatus on the market for use in the study of such small fossils as the Foraminifera. The lamps sold by the manufacturers of

optical apparatus are defective in many respects, the chief of which is that they will not provide a sufficient amount of concentration of the image of the light source upon the object. The best of these lamps have condensing lenses which are supposed to be aspheric or corrected by some other means, but aberrations are always noticeable.

The requirements are simple: (1) an intensity of illumination making it possible for the highest usable powers of binocular microscopes to be employed for hour after hour, month after month, yet without noticeable eye fatigue to the user; (2) an evenly illuminated spot of light covering the entire field of view; and (3) absence of excessive heat to annoy the microscopist. Long study of the problem, accompanied by much experimenting with existing models of illuminators, has led to the conviction that satisfactory equipment provided with a condensing lens cannot be made to fulfill the requirements at a cost that would not be prohibitive. The reasons are obvious to even the novice in optics; the aberrations are hopelessly beyond the power of correction.

These considerations have led to the construction of an entirely different type of illuminator (figs. 53, 54), which apparently has not previously been employed in microscopy. The details of the apparatus are outlined below. It consists essentially of a concave reflecting mirror, a low-wattage concentrated filament lamp, and suitable means for support and adjustment. Seven of these illuminators have been constructed in the laboratories of the California Academy of Sciences and the Associated Oil Company, and have proved satisfactory. They yield a brilliant spot of illumination, without the slightest trace of color aberration and with the diffusion of the image of the filament entirely under control.

Description of Specially Made Illuminator

Mirror: The mirror employed was ground from a 4-inch disk of plate glass, 1 inch thick. The radius of curvature of the concave surface was made 4½ inches, the focal length 2¼ inches. This was polished to a sphere and figured to an ellipse of revolution with 10 inches between the

foci, within narrow limits. This surface was then coated with aluminum, evaporated thereon in a high vacuum by the process lately developed for use on astronomical reflectors. The back was ground to a convex surface concentric with the concave, to even up the thickness of the glass. (Such refinement of construction is not absolutely necessary, but is desirable.) A spherical curve of the same radius is satisfactory for most work, and thinner glass, with the metal deposited on the back, is not very objectionable; the double image thereby obtained will be noticed only by the very critical. With the delicate metal coating deposited on the front surface, care is required to prevent injury; on the back it can be protected with paint. By getting away from a silver surface, the annoyances of tarnishing were completely eliminated; and by means of the elliptical curve, spherical aberration was almost eliminated.

Lamp: After many trials, the lamp that was finally adopted was an ordinary single-pole bayonet-type automobile bulb, rated at 15 candle power. This is operated at 6 to 8 volts from the regular 110-volt A.C. lighting circuit by means of a small transformer. If 110-volt direct current is used, suitable resistance should be included in the circuit. The single filament is a concentrated coil. Such lamps are commonly used on various parts of automobiles. Some manufacturers bake a trademark into the end of the glass bulb. For the present purpose, this is objectionable; it can be removed easily with nitric acid and a small amount of polishing thereafter. This lamp does not produce a sufficient amount of heat, even in a sealed housing, to be objectionable, except at the focal point.

Housing: It is difficult to roll sheet metal accurately and neatly into the form of housing desired. Therefore a casting was made of a light aluminum alloy, the wall thickness being about $\frac{3}{32}$-inch. This was machined on one end with a recess to hold the mirror, and on the other—for the front glass—with a plane parallel circle. Both mirror and glass were sealed dust-tight by means of thin felt gaskets, and all were held in place by means of thin flat snap rings. The outside of the housing was provided with four bosses, the largest one for the lamp support, and three smaller ones spaced 120 degrees apart for the support of the spider. The inside was finished dead black to absorb the small amount of heat from the bulb; the outside was given the usual crackle finish. A $\frac{3}{8}$-inch stud was screwed in the large boss for a side-arm support, and this, in turn, was held in a clamp, movable up and down on a rod of the same size. A ring-type base of cast iron was adopted. The outside of the front end of the housing was machined for holding a support for color screens or cooling cells. Most workers prefer pure, even, white light illumination, but there are situations, especially in photography, in which the interposition of one or more filters in the beam is desirable. The concentration

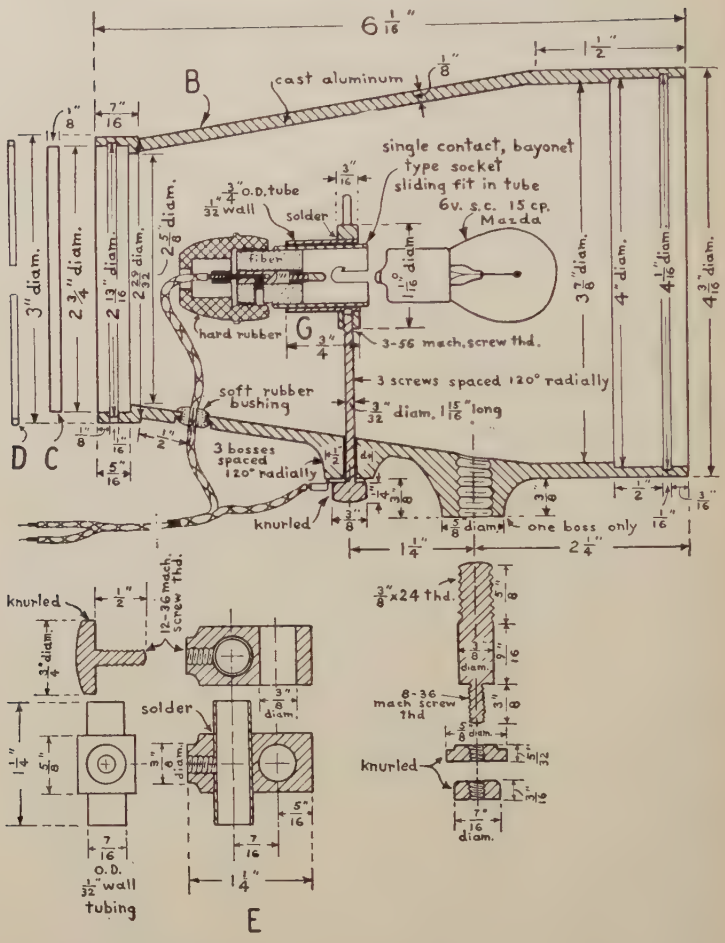
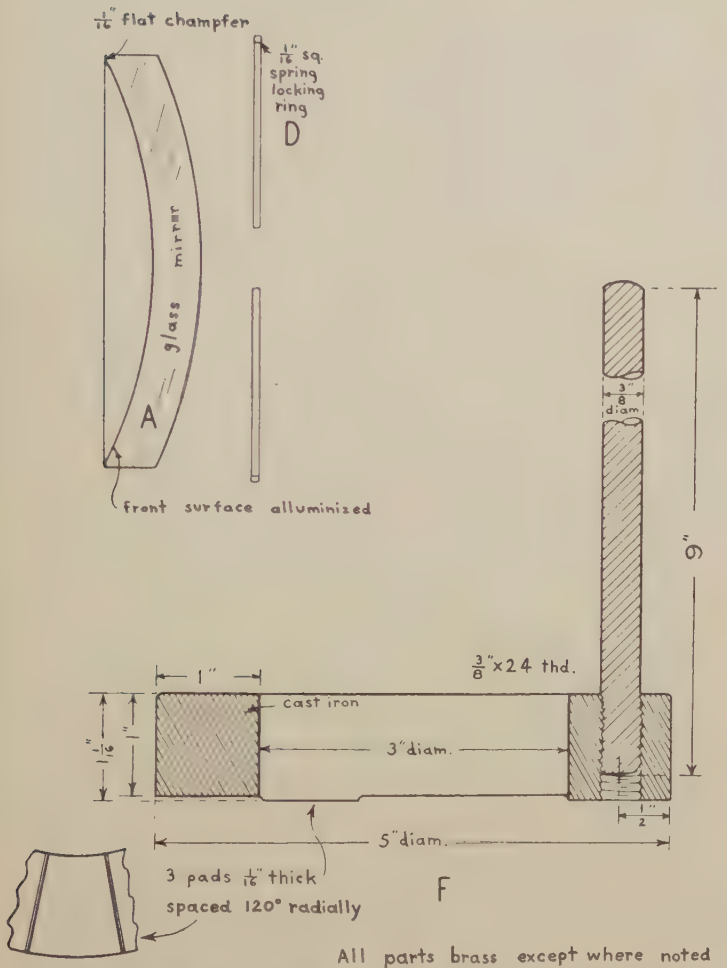


Fig. 53. Reflector type of illuminator for use with low-power microscopes, constructed in the paleontological laboratories of the Associated Oil Company and the California Academy of Sciences by G. D. Hanna, April 21, 1936. Details: *A*, aluminized concave mirror generated by an



eclipse of revolution; *B*, housing; *C*, plane glass front; *D*, snap-spring rings to hold mirror and front glass in place; *E*, details of adjustable support for housing; *F*, base and vertical rod; *G*, spider and lamp assembly.

of the light beam is intense. There can be, of course, no color aberration, and spherical aberration can be reduced to suit the maker of the mirror. The heat of the focused beam is too great for the bare hand, and in some work (but not with microfossils) a cooling cell would be needed. Various types of support for these accessories are satisfactory, such as a split ring with a thumbscrew. In the apparatus here described, part of the ring was separated with two saw cuts and bent down to act as a gripping spring. Compartments 2 inches square were made to suit the available filters. No need has been found for incorporating a diaphragm.

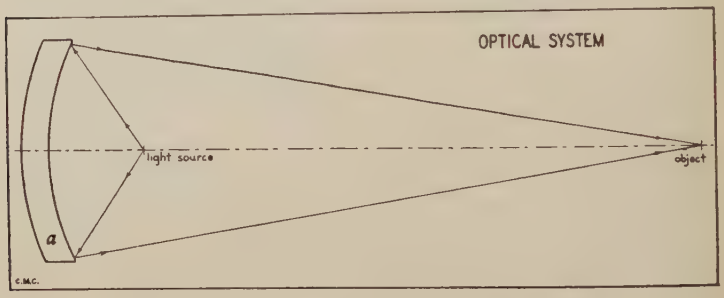


Fig. 54. Optical system of reflecting illuminator.

Spider: In order to enclose lamp and mirror completely, dust-tight, the lamp was supported on a spider. This is a short section of metal tubing with an internal diameter such that the lamp socket is a sliding fit. Part of the tube was sawed to produce a gripping spring. At one end the thickness of metal was increased so that three centering screws could be attached through the housing bosses, and adjustment made. By such an arrangement, forward and back focusing as well as accurate centering is provided for (Hanna, 1937).

It would be impracticable to consider here in greater detail all the devices and methods which have been employed in the past for use with the Foraminifera. Readers who wish additional information will find it profitable to consult the excellent work on the subject by Cushman (1928). An early account of a laboratory designed for use in economic work and the methods then employed was published in 1924 (Hanna and Driver; see also Hanna, 1927). Much of the equipment and many of the processes then in use have since been either improved or superseded.

Diatoms, Radiolaria, etc.—Those microscopic animals and plants which use silica instead of calcite in the building of their skeletons are often found fossilized in deposits of enormous thickness. Rocks containing them are usually acidic, the matrix material very often being rhyolitic volcanic ash, and they occur in all stages of chemical metamorphism to cherts and jaspers. With hard rocks such as the last named, the technique involved in preparation for study consists of making thin sections and polished surfaces as in petrography. Radiolaria are sometimes well preserved in these rocks and can be studied effectively, but the diatoms have almost always been destroyed.

Collections of the less altered rocks are usually made in the field in the same manner as has been described for Foraminifera. It is extremely desirable that all important locality information should be recorded and that such stratigraphic notes be made as will be useful in an understanding of the particular conditions involved. Paper envelopes are generally used for such samples.

The method of preparing the siliceous fossils for study differs radically from that which has been described for Foraminifera. When Foraminifera are present with the diatoms and other fossils it is best to use a separate part of the sample for each of the different classes. If this is impractical, the Foraminifera should be removed from the sample by the usual process, except that the finer materials should be saved from the screens.

The reasonably dry sample is broken into small fragments of from 5 to 10 mm. in greatest dimension and placed in a beaker or flask. A quantity of concentrated hydrochloric acid two or three times the volume of the sample is added and the sample is boiled in this solution under a hood for from fifteen minutes to one hour. After the hydrochloric acid has taken up all the mineral matter it is likely to remove, it is poured off, and usually without any intermediate washing an equal amount of concentrated nitric acid is added to the sample.

Sometimes it is best to mix the nitric and hydrochloric acids in equal proportions and boil the sample in the resulting aqua regia until no further mineral is taken up. Then the liquid is poured off and the sample is thoroughly washed in numerous changes of water in order to remove all the salts of calcium which may have gone into solution; otherwise they will be precipitated in subsequent treatment.

Next, the sample is boiled in concentrated sulphuric acid for a period of time varying from a few minutes with highly siliceous samples containing very small amounts of organic material to one hour or more when a large amount of such substance is present. The chief function of sulphuric acid is the removal of carbonaceous material, but part of the minerals also passes into solution. All the boiling in acids must be done under a hood, or, with sulphuric acid, a reflux condenser may be employed.

If any perceptible quantity of organic material is present, the sulphuric acid will turn dark brown or black with colloidal carbon. The destruction of this carbon is rather difficult while the acid is hot, but when it cools small crystals or powder of sodium nitrate or potassium chlorate may be added, which will effectively oxidize and decolorize the liquid. When cool, the sulphuric acid may be poured off into a beaker containing a large volume of water. The fossils are not attacked by any of the treatments indicated.

It is important to remove the acid and such materials as may be in solution as effectively as possible at this stage. This will require washing the samples in several changes of fresh water. Ordinarily, the fragments of rock or shale will have lost any dark color they originally possessed and will become white or pale buff. The treatment thus far will have produced little, if any, disintegration unless there may have been a fair quantity of carbonate present in the original sample; the rapid evolution of carbon dioxide will then sometimes effect a certain amount of dissociation of particles of rock.

In order to disintegrate the sample, it is usually covered

with two or three volumes of water to which are added a few small flakes of sodium hydroxide. Boiling in this caustic may be continued for a few minutes without damage to the siliceous fossils, but strong alkalies and long boiling are to be avoided. The hydroxide will usually start disintegration and may even carry it to completion. Often, however, there are present some iron compounds which seem to form a sort of gel and mask the effect of the alkali; it is then best to pour the solution off the sample, add instead a small quantity of hydrochloric acid, and boil for a few minutes. This is then poured off, either into the beaker which contains the alkali or into another, and the alkali treatment is again repeated. Sometimes it is necessary to repeat the entire process several times before a sufficient amount of disintegrated material will have been obtained from the lumps of rock.

As the work progresses, material is collected in one beaker, and it will be found that when the hydroxide concentration is even exceedingly small all the fine materials will flocculate and settle rapidly to the bottom. No separation of the débris and the fine clay minerals from the fossils can then be effected. A small quantity of hydrochloric acid will neutralize the hydroxide and effectively break up the flocculation.

At this point decantation begins, and with the aid of the microscope samples are taken from time to time with a clean pipette. The fossils present are so small that they cannot be separated from the associated minerals by screens, and decantation is the only method which has thus far been found satisfactory. In commercial practice where large quantities of diatomite are handled a measure of separation is effected by the use of a blast of air, but this is extremely ineffectual and does not produce a sample in any way comparable to one prepared by the decantation method.

Extreme care must be taken at all stages to prevent contamination of the sample. Ordinary tap water is so filled with diatoms that they will concentrate noticeably in the sample unless filtration has been employed immediately before use.

Sometimes the fresh-water diatoms will not seriously interfere with work on hand, but permanent preservations should be free from them; otherwise, a worker handling the material at a later time will be unable to distinguish between the fossil forms and the living forms introduced by the careless process of preservation. Distilled water is the safest to use, but it cannot always be obtained in sufficient quantity.

Several repetitions of the decantation will usually remove all the fine material and débris that can be separated without excessive loss of fossils. If heavy sand grains are still present they can be removed by the same method, except that the time of settling is gauged so as to allow only the sand grains and a few of the heavier fossils to settle. This usually must be repeated a few times to make a good separation and even then a few large diatoms or Radiolaria may remain with the sand. If desired, this sand can be examined and a selection of the forms made at a later time.

The foregoing is the author's method of treatment for most shale deposits containing siliceous organisms. Circumstances may require some variation, but this can only be determined by long practice in preparation. There are about as many variations in the process as there are workers in these groups of fossils, but almost all of them agree in the use of the three acids mentioned. Sometimes when a large quantity of organic matter is present, potassium bichromate crystals are added to the boiling sulphuric acid. The literature on diatoms contains many accounts of methods of preparation, or modifications of those already in use; I do not think it necessary to repeat them, because the one outlined above has proved successful in practice.

Cleaned samples are stored in glass containers of some kind. Some workers use glass-stoppered bottles, others those with screw tops. Cork stoppers are undesirable because the preserving fluid will eventually dissolve the cork and form products that will interfere with the mounting processes to be followed later. Some workers use about 70 per cent alcohol

for the permanent preservative fluid, but the present writer prefers distilled water with a few drops of formaldehyde, because the subsequent mounting operations are thereby made easier.

A study of the siliceous fossils requires different equipment from that used with larger forms. There is almost no limit to the sum that can be expended for instruments of various kinds, all of which are useful at times. The one absolutely necessary piece of equipment is a compound microscope with a supply of slides, cover glasses, and mounting media. Such small objects as siliceous fossils have heretofore been studied almost entirely by transmitted light. The type of microscope to be preferred depends entirely upon the degree to which a study of the fossils is to be carried. For the higher type of scientific work the best modern compound microscope is none too good. In ordinary routine studies achromatic objectives of 16, 8, 4, and 2 mm. focal lengths are entirely satisfactory. For the highest resolution and for photography, apochromatic objectives with higher numerical aperture are to be preferred. Visual work can usually be carried on in daylight, but this is far from satisfactory when the compound microscope is used. It is better to use an ordinary frosted electric-light bulb provided with a green screen.

A study of siliceous fossils leads immediately to the study of microscopy, itself a subject too broad to be treated in any detail here. The student should master the principles of this science through the use of some such texts as those of Belling (1930) and Spitta (1920).

The most common method of mounting the fossils is to make strewn slides. To do this, a drop of the sample containing the fossils is placed on a cleaned cover glass of approximately .17 mm. thickness. This is diluted on the cover by the use of a jet of distilled water from a micropipette. The fossils are allowed to settle, evenly distributed over the surface of the cover, and the water is allowed to evaporate with gentle heat but without boiling. A drop of mounting medium is

added to the cover, and the solvent is evaporated by heat usually applied from a hot plate of some sort. After the solvent is removed from the mounting medium so that the latter becomes completely hard upon cooling, the cover is placed on a cleaned slide. This, in turn, is gently heated over the hot plate until adhesion is obtained and the mounting medium flows to the edge of the cover. Upon cooling, the slide is ready for study, with the diatoms or other fossils in optical contact with the under side of the cover glass.

It is undesirable to mount the objects on the slide itself, because when the thickness of the mounting medium and the cover are added together the total of material between the object and the objective is far beyond the possibility of correction in any ordinary microscope.

Careful students insist upon selecting cover glasses which are of the correct thickness to match the construction of the particular objectives in use and they indicate the thickness of the cover on the label. As a rule, this procedure is not necessary for the use of low powers, but if any magnification as great as that obtained with an 8-mm. objective or greater is to be employed, the precautions indicated are very important. If covers of unknown thickness are used, some little time must be spent in properly adjusting the tube length of the microscope or the correction collar which is provided on some objectives, in order to make the necessary correction.

Because of the low index of refraction of the mounting media usually used in biology these have been almost completely superseded in the study of siliceous organisms. Styrax, a natural balsam, was used for many years, and many hundreds of other preparations have been tried. The highest possible resolution at present obtainable with visual radiation is by the use of realgar, which has an index of refraction of 2.4. This substance is highly colored and so difficult to use that in general other materials are to be preferred. White phosphorous makes an excellent mounting medium and has an index of refraction of approximately 2.0, but it is difficult

and dangerous to use unless extreme care is taken. The synthetic resin, hyrax (Hanna, 1930), having an index of refraction of 1.7135 for the light ray with a wave length of 0.589μ (sodium light) (see Cameron, 1934), has come into general use in recent years. It is soluble in the usual solvents of Canada balsam and is employed essentially in the same manner.

A general idea of the forms of diatoms, radiolarians, and silicoflagellates found in a given deposit can be obtained from a few strewn slides, but for a thorough investigation it is better to make individual mounts of each species or of groups of specimens picked out systematically. Elaborate methods have been developed for this purpose, but a mechanical finger of some sort is a first essential. The writer prefers for general work a model which can be clamped on the stage of the microscope. A glass tube or a rod is drawn out to an extremely fine point and this point is focused under the objective of the microscope. It has controlled motion up and down and sideways by means of screws.

A thin distribution of the fossil material is made on a glass slide ruled in parallel lines either vertically or horizontally, the distribution being effected in the same manner as described above for cover glasses. One of these slides is searched thoroughly and systematically, line by line, and the specimens which it is desired to save are picked up by lowering the point of the glass hair and manipulating the slide with the fingers against it. After a little practice it is not difficult to pick up extremely small species when one is working under a 16- or 8-mm. objective. Selected specimens are transferred to one end of the slide or to a vacant space in the center and when all that are desired have been so assembled they are removed to a prepared cover and arranged in a suitable manner. The cover has a minute circle of India ink ruled in the center on an extremely thin film of gelatin or gum tragacanth. The film is obtained by allowing the least possible layer of a dilute solution to evaporate. When they are in position, specimens are fastened down to this film merely by breathing very

lightly upon the cover. The moisture of the breath is enough to cause excellent adhesion. A drop of mounting medium is then added, the solvent is evaporated, and the cover is reversed upon the slide. All the precautions customary for the preparation and preservation of permanent museum material are, of course, taken in numbering and labeling specimens.

The method outlined above is sufficient for routine work in most laboratories and is rather rapidly carried out. Usually in a day's time 300 or 400 individually selected specimens can be mounted and grouped on a few covers.

If, however, the very best possible preparations are desired, an entirely different procedure must be followed. The one best known is called, after its founder, the "Cabellero" (1897, etc.) technique. The article describing it is too long to be reproduced in full and cannot be shortened without omission of essential details; the reader is therefore referred to it for complete information. The process involves the use of a dish of mercury on the stage of the microscope and an inverted bell jar attached to the tube. All the selecting and arranging for the permanent slide is done in this dust-free atmosphere and extremely beautiful preparations can be made. One of the most expert advocates of the method in America is William M. Grant, of San Francisco.

A most complete account of the methods employed in the preparation of diatoms, living and fossil, is that published by Hustedt (1929). This work contains many references to the literature on the subject. Van Heurck (1896) and Albert Mann (1922) have also treated the subject in great detail.

Thin sections and polished surfaces.—Frequently, when fossils are embedded in hard matrix an adequate knowledge of their structure and relationships can only be obtained by making a polished surface of the rock, or even a thin section. The fossils thus studied do not belong to any certain group and may vary from the largest to the smallest. As a general rule the softer rocks are easier to prepare than hard ones, but the essential technique is the same for all.

Sections of Foraminifera are often made merely by attaching the specimens to a small stick with shellac and rubbing them down to the desired plane on a fine-grained carborundum stone. This process is sometimes used in the field for the study of the central chambers of the orbitoid and fusilinid Foraminifera.

For most purposes, however, more elaborate equipment is required and some sort of revolving lap is almost a necessity. Many forms of these have been devised; two that are satisfactory for the usual laboratory and economical to build and operate are illustrated (figs. 55–56). These have a horizontal metal surface revolving inside a pan, and the grinding is done with wet carborundum powder and water. Coarse grains are used for roughing, and fine grains such as No. 600 for the last grinding. Polishing is usually done on a revolving cloth surface with tin oxide, iron oxide, or chromium oxide. Several forms of equipment are in use for the sawing of the rock, either to get a flat surface to begin with or to make a thin chip from which a section is to be ground. The technique involved in making thin sections is the same as that used in the study of rocks and minerals, and has been well described (Boddy, 1934; Farris, 1932; Gäckel, 1930; Grayson, 1910; Holmes, 1930; Johannsen, 1918; Keyes, 1925; Merrill, 1895; Rogers and Kerr, 1933; Ross, 1924, 1926; Schaffer and Hirst, 1930; and Weymouth, 1928). Wentworth and Suzuki (1936) describe a method of making several thin sections at the same time.

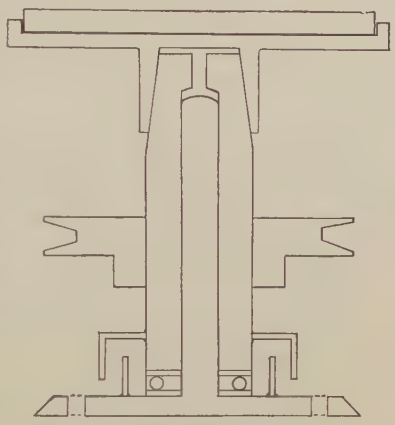


Fig. 55. A form of bench-grinding lap suitable for paleontological work.

Almost every worker with thin sections devises equipment and methods to suit his particular needs. A binocular microscope is satisfactory for the study of almost all polished surfaces, but the thin sections are best studied with transmitted light and a compound microscope. A petrographic micro-

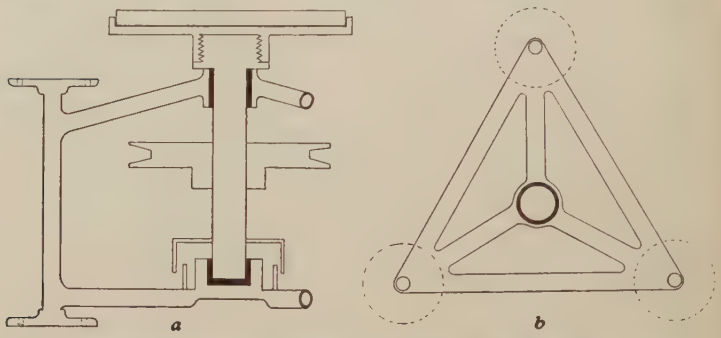


Fig. 56. *a*. Another form of bench-grinding lap, easy and economical to construct and operate. *b*. Base of bench-grinding lap.

scope is not usually needed, but it is an aid in determining the nature of the replacement material, matrix rock, or other substances.

Probably the most common groups of fossils studied as thin sections and polished surfaces are corals, graptolites, and petrified woods.

Miscellaneous groups of animals and plants.—Besides the groups of animals and plants already mentioned, there are several others of varied and sometimes uncertain nature which, as fossils, properly fall into the science of micropaleontology. These include the following.

A. Pollen: Study of pollen in peat deposits and coal beds has assumed wide importance during recent years in the determination of climate and the distribution of floras of the past. Methods of preparation worked out by Lagerheim and von Post (see Erdtmann, 1921) have come into general use. The material is digested in a weak solution of potassium hydroxide, after which it is washed through a fine screen.

Eventually it is collected into a tube and centrifuged to hasten settlement. It may be preserved in distilled water to which a trace of formaldehyde has been added, or in alcohol of about 70 per cent strength. Studies are made with a compound microscope and transmitted light. Usually, strewn slides of the material are made, the mounting medium being balsam. However, in the opinion of many investigators, for the analytical studies and the plotting of curves of frequency, permanent preparations are not needed. A drop of the liquid containing the pollen grains is transferred to a slide, and a cover glass is carefully placed so as not to disrupt the frequency arrangement of large and small grains. If the quantity of the original material is known, a count of the grains in a specified area of the slide will yield data from which a frequency curve may be drawn. This method is at best only qualitative. Improvements have recently been suggested by Erdtmann and Erdtmann (1933), and Erdtmann (1934), which are expected to give more data of a quantitative nature. They suggest the destruction of the lignin and humic acids of the sample by oxidation. This is followed by the hydrolysis of the cellulose materials by hydrochloric acid, leaving the most resistant parts of the sample, such as pollen, spores, and fragments of cuticle. They recommend that the actual counts be made on a slide ruled as a net. Von Post (1933) has indicated that the treatment to which the pollen is thus subjected is quite severe and may result in the destruction of some of the grains and in the distortion of others. Refinements are suggested by Kirchheimer (1933), who finds that photographs of pollen preserved in Canada balsam lack contrast. By using the Burris India ink bacteriological technique, the pollen grains appear brilliantly on a dark background, and the details of structure can be more clearly seen.

B. Scales and otoliths of fishes: Much attention has been given to the application of these objects in the correlation of geologic formations in various regions. They rarely occur together, but are found scattered through various types of

rocks from the Paleozoic upward. Although the objects are properly classified among the vertebrates, a study of them falls within the realm of microscopy.

In the older rocks, collections are often made from limestones and calcareous shales, usually of marine origin. No special technique is required other than the cracking and splitting of the rocks with suitable hammer or chisels, the specimens desired being saved for permanent preservation in cabinet trays.

In western North America there are several formations in which an abundance of fish scales is to be found, although completely associated skeletons of these animals are rarely present. Other fossils are rare in these formations, so that the scales are the most readily available fossils for correlation. Not nearly so much use has been made of them in the past as their abundance and importance would seem to warrant, a situation probably resulting in part from the fact that there is no suitable classification of the objects. Biologists in general, and ichthyologists in particular, rarely take notice of the scales of fishes in arranging systems of classification. Professor T. D. A. Cockerell has commented on this situation in some of his papers and has pointed out some of the problems in biology as well as in geology which can be solved by a study of the scales. He has shown that the scales of a particular fish exhibit little variation in their fine sculpturing, irrespective of the part of the animal from which the scale was derived. This of course excepts the series of lateral-line scales, which are usually quite different. When a good-sized collection of scales of living fishes is available for comparison, one has little difficulty in placing in its proper family the fish from which a given fossil scale is derived, and usually it is possible to allocate it to its proper genus. It is unfortunate indeed that students of fishes, in arranging their classifications and describing genera, have failed to take note, as a rule, of the characters disclosed in the scales. In order to get around this difficulty some paleontologists have devised

makeshift systems, assigning to group letters and figures the different types found in the formations being studied.

The Maury shale in the Rocky Mountain region, the Moreno shale, Kreyenhagen shale, Monterey shale, and some parts of the Tulare formation of California are particularly rich in fish scales. The preservation is often extremely good. Collections are usually made in the field in bulk and preparation for study is completed in the laboratory. The shales usually split readily along bedding planes, and in making collections it is desirable to use care so that the sculptured side of the scales may be preserved. Often only the impressions of the scales may be present in the shales, but these usually display the fine sculpture as well as does the scale itself. The degree to which the study of these objects may be carried is indicated by work on the scales of living Pacific Coast salmon in the last few years. The fine sculpture of the scales apparently tells not only the species of the fish from which a particular scale was derived, but also the age of the animal when the scale was taken, the length of time spent in fresh water prior to its descent to the sea, and not infrequently the actual river, creek, or lake in which it was reared.

One method has been devised for preparing the scales in the laboratory for study, and because this has proved satisfactory it will be described. It consists of sawing a "button" out of the shale, with the scale in the center. For this work, hardened steel tubes with teeth have been found unsatisfactory because of rapid wear. A soft steel or brass tube set with small diamonds makes an excellent tool and will last almost indefinitely. Because of the difficulty of obtaining such equipment, a tube made of carborundum is generally used and will give satisfaction for a long time. A thin-walled tube about ¾-inch to 1 inch in diameter inside and from 1 to 1½ inches long is excellent (fig. 57). These tubes are available on the market molded around a shaft which can be attached with a chuck to a motor spindle or used in a small drill press. To remove the scale, the saw cut is made about ⅛- to ¼-inch

deep in the slab of shale; the "button" is pried loose with a flat tool such as a small chisel, and the bottom is ground flat on a carborundum stone.

For permanent preservation it has been found desirable to paint the "button" with dilute cellulose-acetate cement, after which it is cemented on an ordinary 1 by 3-inch glass microscope slide with the same material, undiluted. When equipment for sawing a circular disk is not available, an alternative method of extracting the scale is to carve, or saw with a hacksaw, a small truncated pyramid from the shale with the scale on the apex (fig. 58). The pyramid is treated in the same manner as indicated for the disk. Excellent preparations can be arranged and classified in standard slide boxes in the same manner as other microscopic objects.

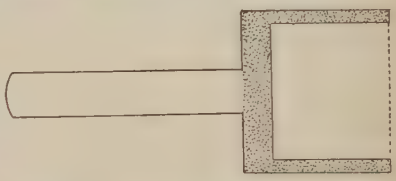


Fig. 57. Carborundum-tube type of cutter for sawing out fish scales.

Otoliths, the earbones of fishes, are abundant in some formations, but usually no effort is made to save or study them except when they occur in sediments that can be readily disintegrated. They are usually prepared for study by the methods employed in the preparation of Foraminifera, which have been outlined above. In many regions these objects are rarely encountered, but in others they form an important part of the fossil concentration resulting from the washing of shales, and an appreciable amount of literature has accumulated from the study of them. (See especially Frost, 1928, 1933*a*, *b*.)

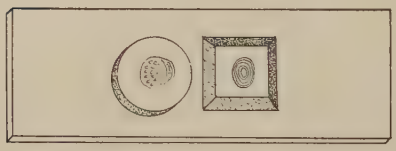


Fig. 58. Slide for preserving fossil fish scales.

C. Conodonts and polychaetes: Many of the shales, sandstones, and limestones of the Paleozoic contain small tooth-

like objects, phosphatic or chitinous in nature and often extremely abundant. These are properly considered as microfossils and they have assumed some importance in paleontology because of their reliability as horizon markers. Much study has been given to them of late years at the University of Minnesota and the University of Missouri, and by the United States Geological Survey. The exact nature of the animals to which these objects belonged is unknown and there has been much discussion of whether they may have been cyclostomes, marine worms, mollusks, or fishes.

The technique employed at the University of Missouri has been well outlined by Branson and Mehl (1933–1934) in a recent publication, and that used at the University of Minnesota by Dr. Clinton R. Stauffer has been supplied for quotation here.*

The technique employed at Minnesota is very similar to that used by Messrs. Branson and Mehl. Samples are reduced by boiling, sometimes a little sal soda being added when the material is of an indurated nature. The disintegrated material is then washed through screens and dried over a radiator or sand bath, and the conodonts separated by the use of bromoform in a separatory funnel. The concentrates, consisting of conodonts and heavy minerals, are drawn off into filter paper placed in funnels below the separatory apparatus. The residual material is handled in the same manner. The alcohol is flushed through both portions to remove the bromoform. The bromoform is reclaimed by washing out the alcohol in water. A glass funnel with a piece of rubber tubing and a pinch cock attached are most adaptable for handling materials for separation. They are inexpensive to construct, are easily cleaned, and larger samples can be handled than in a separatory cylinder of the Penfield type.

The technique employed for the Polychaeta is similar to that used for Foraminifera. The argillaceous shales are soaked in water to break down the material, then washed through screens, dried and the specimens picked out by the aid of a No. 00 sable hair brush. These fossils are chitinous and hence cannot be separated by the use of heavy liquids as can the conodonts.

Branson and Mehl (1933–1934) have given much general information on conodonts, their occurrence, value, and preparation for study. It may be noted that they use tetrabrome-

* In a letter from Mr. Harlan R. Bergquist, dated May 18, 1935.

thane as the heavy liquid to float off the lighter minerals. The heavy residue is caught on a filter paper, washed first with naphtha to remove the heavy liquid, then with chloroform to remove the naphtha. Sometimes as much as a gallon of the original sample will give only about a thimbleful of concentrate, made up, in large part, of conodonts. At times a heavy mineral such as pyrite will predominate in the residue. A further separation is then made, the teeth being floated off in a denser concentration of liquid. A thin solution of the commercial cement called "Ambroid" is frequently used in fastening the specimens to the slides. It is often desirable to study a specimen immersed in oil in order to see certain details, and for this purpose a solution of anise oil in xylene, one to four, has been found satisfactory. The methods employed by these authors in drawing, photographing, and filing specimens are extremely interesting and well worth careful study. In view of the importance of these fossils in the Paleozoic sediments it is believed that a few references to the literature may be useful to the reader. (See Branson and Mehl, 1933–1934; Gunnell, 1931; Loomis, 1936; Schmidt, 1934; Stauffer, 1933; and Ulrich and Bassler, 1926.)

BIBLIOGRAPHY

ABEL, OTHENIO

1925. Geschichte und Methodik der Rekonstruktion fossiler Wirbeltiere. Jena: Gustav Fischer, viii + 327 pp., 225 figs.

ADAMS, ANSEL

1935. Making a photograph: an introduction to photography. London: The Studio Limited; New York: The Studio Publications, Inc., 96 pp., 7 figs., 33 pls.

AEBY, C.

1878. Das histologische Verhalten fossilen Knochen- und Zahngewebes. Arkiv f. Mikros. Anat., Bonn, 15:371–381, pl. 23.

ALEXANDER, C. I.

1933. Preparation and study of fossil Ostracoda. Micropaleont. Bull., 4:1–11.

BACHOFEN-ECHT, A.

1925. Mikrophotographien von Bernsteininsekten. Pal. Zeitschr., 9: 162–163.

BANNISTER, F. A.

1934. The preservation of pyrites and marcasite. Mus. Jour. [London], 33:72–75. [Specimen is soaked in a mixture of 7 per cent (by weight) of tartaric acid in acetone and toluol (equal parts). It is then placed in an aqueous solution of ammonia, washed in water, and dried with alcohol.]

BATAAFSCHE PETROLEUM MAATSCHAPPIJ LABORATORY

1935. Recovery of Foraminifera by means of flotation. Jour. Paleo., 9:745–746.

BATHER, F. A.

1908. The preparation and preservation of fossils. Mus. Jour. [London], 8:76–90.

BELLING, JOHN

1930. How to use the microscope. New York: McGraw-Hill Book Company, xii + 315 pp., 28 figs.

BERNARD, H. M.

1894. On the application of the sand blast for the development of trilobites. Geol. Mag. London, 1:553–557, 2 figs.

BODDY, R. G. H. B.

1934. The preparation of thin sections of coal using Bakelite as an embedding medium. Fuel, 13:269–271.

BOETTCHER, F. L. J.

1912. Preservation of osseous and horny tissues. Proc. U.S. Nat. Mus., 41:697–705. [Recommends infiltration with paraffin. Bones are

hung in a large boiler (water bath) and allowed to soak in hot paraffin for from two hours to a week or more, depending upon the size and permeability of the bone.]

Böse, E., and Vigier, Victor von
1907. Ueber die Anwendung von Ätzkali beim Präparieren von Versteinerungen. Centralbl. f. Min. Geol. Pal., Jhg. 1907:305–313.

Branca, W.
1906. Die Anwendung der Röntgenstrahlen in der Paläontologie. Abhandl. preuss. Akad. Wiss. (math.-phys.), Berlin, 55 pp.

Branson, E. B., and Mehl, M. G.
1933–1934. Conodont studies. Univ. Missouri Studies, 8:1–349, 28 pls. [Issued in 4 nos.]

Brough, James
1931. On the fossil fishes from the Karroo System, and some general considerations on the bony fishes of the Triassic period. Proc. Zoöl. Soc. London, 1931:235–296, 19 figs., 4 pls. [With a note by D. M. S. Watson on the use of the wire brush in cleaning specimens.]

Brouwer, H. A., *et al.*
1925. Practical hints to scientific travelers. 2d ed. The Hague: Martinus Nyhoff, 122 pp., illus. [Contains chapters of special information on the East Indies, Africa, and the Philippines.]

Buckman, S. S.
1911–1912. A method of removing the test from fossils. Am. Jour. Sci., 32:163; 33:593–594.

Bulman, O. M. B.
1925. Notes on the structure of an early *Dictyonema*. Geol. Mag., 62: 50–67, 12 figs. [Methods of cutting serial sections of graptolites.]

1926. On *Branchiosaurus* and allied genera (Amphibia). Proc. Zoöl. Soc. London, 1926:533–579, 15 figs., pls. 1–4. [Outlines a method of reconstruction of crushed skulls by building up the sections from squeezes.]

1931. Note on *Palaeospondylus gunni*, Traquair. Ann. and Mag. Nat. Hist., 8:179–190, 5 figs., pl. 4. [Describes a noteworthy method of decomposing the matrix with acid and transferring the free specimen to a microscope slide.]

Butler, A. J.
1933, 1935. Cellulose films in Paleontology. Mus. Jour. [London], 33: 235; 35:111. See also Nature, March 30, 1935.

CABALLERO, ERNEST

1897. Técnica de las preparaciones microscópicas sistemáticas. Anal. Soc. Esp. Hist. Nat., 26:217–241. [Translated into French by J. Tempère and reprinted in Le Micrographe Préparateur, vol. 6, no. 3, 1898, pp. 112–118; no. 4, pp. 156–164, 1 fig.; no. 5, pp. 193–197, 1 fig.; no. 6, pp. 251–255. Reprinted in Spanish in 1925 by the "Junta para la amplicación de Estudios" with a prologue by Dr. Cajal. Translated into English by Frederick Adams and reprinted with prologue by Dr. C. Tierney in Jour. Roy. Micr. Soc., 47:9–28, 19 text figs., pls. 2–5.]

CAMERON, E. N.

1934. Notes on the synthetic resin, hyrax. Am. Mineral., 19:375–383, 2 pls.

CARROLL, D. L.

1929. Scientific apparatus and laboratory methods. New methods in the study of fossil shark teeth. Science (n.s.), 70:331–332. [Making of sections.]

CASE, E. C.

1925. The use of Bakelite in the preservation of fossil material. Science (n.s.), 61:543–544.

COOPER, C. L.

1935. Ammonium chloride sublimate apparatus. Jour. Pal., 9:357–359, 2 figs.

COOPER, G. A.

1933. A method for the preparation of fossils. Science (n.s.), 77:394.

CULLISON, J. S.

1934. A suitable tray for comparative examination of minute opaque objects under the binocular microscope. Jour. Pal., 8:247.

CUSHMAN, J. A.

1925. An introduction to the morphology and classification of the Foraminifera. Smithsonian Misc. Coll., vol. 77, no. 4.

1928. Foraminifera, their classification and economic use. 1st ed. Spec. Publ. no. 1, Cushman Lab. Foram. Res., 403 pp., 58 pls. [2d ed., 1934, 2 vols., 426 pp., 71 pls.]

DAVIDSON, C. F.

1933. Hardening fragile fossils with vinyl acetate. Mus. Jour. [London], 32:455. See also Trans. Perthshire Soc. Nat. Hist., 9:67.

DEBES, E.

1910. Zur Technik der Foraminiferenpräparation. Sitzungsber. Naturf. Ges., Leipzig, 37:3–34.

Drevermann, Fritz

1928*a*. Bemerkungen zu den Präparationsbeobachtungen. Ber. Senck. Naturf. Ges., Frankfurt a. M. (Natur u. Museum), 58:121–124.

1928*b*. Beobachtungen bei der Präparation von Solnhofener Versteinerungen. Pal. Zeitschr., 10:289–292, 2 figs.

1930. Wie man Skelette fossiler Wirbeltiere montiert. Ber. Senck. Naturf. Ges., 60:469–473, 10 figs.

Edinger, Tilly

1925. Photographie verschwundener Weichteile. Pal. Zeitschr., Bd. 7, Hft. 2, pp. 141–144, 4 figs.

Efremov, G. A., and Kuzmin, F. M.

1931. Preparation of remains of the oldest Tetrapoda in hard rock. Acad. Sci., U. S. S. R., Proc. Paleont. Inst., 1:223–234. [In Russian. Describes the methods used in Sushkin's laboratory.]

Ehrenberg, Kurt

1929. Erhaltungszüstand und Vorkommen der Fossilreste und die Methoden ihrer Erforschung. In E. Abderhalden, Handb. Biol. Arbeitsmeth, Abt. 10, Meth. Geol. Min. Pal. Geogr., Hft. 7, Lief. 310, pp. 751–882, 30 figs.

Elias, M. K.

1935. Tertiary grasses and other prairie vegetation from high plains of North America. Am. Jour. Sci., 29:24–33, 1 "plate" on p. 28 of text.

Erdtmann, G.

1921. Pollenanalytische Untersuchungen von Torfmooren und marinen Sedimenten in südwest Schweden. Arkiv f. Botanik, Kg. Svenska Vet. Akad., 17:1–171, 11 pls.

1934. Ueber die Verwendung von Essigsäureanhydrid bei Pollenuntersuchungen. Svenska Bot. Tidskr., 28:354–358.

Erdtmann, G., and Erdtmann, H.

1933. The improvement of pollen-analysis technique. Svenska Bot. Tidskr., 27:347–357.

Farris, E. J.

1932. Aloxite as an abrasive for grinding bone sections for histological purposes. Science (n.s.), 75:389–390.

Feifel, K.

1930. Ueber Foraminiferen der Schwammkalke des schwäbischen weissen Jura. Pal. Zeitschr., 12:42–47.

Fenton, M. A.

1935. Nitro-cellulose sections of fossils and rocks. Am. Midland Naturalist, 16:410–412.

FIGGINS, J. D.

1931. A proposed standard of viewpoints from which to illustrate horned and antlered mammal skulls. Proc. Colo. Mus. Nat. Hist., 10:22–24, pls. 1–3.

FISCHER, E.

1914. Zur Anwendung der Röntgenstrahlen in der Paläontologie. Mitteil. Naturf. Ges., Halle, Bd. 4, pp. 1–8.

FISHER, R. A.

1932. Statistical methods for research workers. 4th ed. London: Oliver and Boyd, xiii + 307 pp., 6 figs., 71 + vi tables.

FRAAS, EBERHARD

1910. Der Petrefaktensammler. Ein Leitfaden zum Sammeln und Bestimmen der Fossilien Deutschlands. Stuttgart: K. G. Lutz, 276 pp., 139 figs., 72 pls.

FRANKE, A.

1922*a*. Die Präparation von Foraminiferen und anderen mikroskopischen Tierresten. Mit Beiträgen. In Keilhack, Lehrbuch der praktischen Geologie, Stuttgart, 2:509–533.

1922*b*. Das Sammeln und Aufbewahren der Foraminiferen und Ostrakoden. Mikrokosmos, Stuttgart, 16:31–33, 70–73.

1928. Mikrofossilien, ihre Gewinnung und Aufbewahrung. Aus der Heimat, Stuttgart, 42:357–365.

1930. Die Trennung der Mikrofossilien aus sandigen Schlämmrückständen mit Tetrachlorkohlenstoff. Zeitschr. f. Geschiebeforschung, 6:162–164. Pal. Zeitschr., 12:312–314.

1935. Ein einfacher Auslesetisch für Mikrofossilien. Senckenbergiana, 17:87.

FRENTZEN, K.

1932. Ueber Durol, ein neues Konsiervungsmittel für fossile und subfossile Knochen und andere mürbe oder leicht zerfallende Fossilien. Centralbl. Min. Geol. Pal., Abt. B, Jhg. 1932:65–66.

FROST, G. A.

1928. Otoliths of fishes from the Tertiary formations of New Zealand, and from Balcombe Bay, Victoria. Trans. Proc. New Zealand Inst., vol. 59, pt. 1, pp. 91–97, 15 figs.

1933*a*. Otoliths of fishes from the Lower Tertiary formations of southern England. I. Isospondyli, Apodes, Berycomorphi. Ann. Mag. Nat. Hist., 12:387–396, 1 pl.

1933*b*. Otoliths of fishes from the Tertiary formations of New Zealand. Trans. Proc. New Zealand Inst., vol. 63, pt. 2, pp. 133–141, 46 figs.

Gäckel, E.

1930. Ueber die Herstellung von Anschliffen an Gesteinen, Erzen, Glas, Knochen, USW. Blätter für Untersuchungs- u. Forschungsinstrumente, 4:1–10, 6 figs.

Gilmore, C. W.

1932. On a newly mounted skeleton of *Diplodocus* in the United States National Museum. Proc. U. S. Nat. Mus., vol. 81, art. 18, pp. 1–21, 6 pls., 3 figs.

Graham, Roy

1933. Preparation of paleobotanical sections by the peel method. Stain Technology, 8:65–68.

Grayson, H. J.

1910. Modern improvements in rock section cutting apparatus. Proc. Roy. Soc. Victoria (n.s.), vol. 23, pt. 1, pp. 65–81, pls. 14–17. Reprinted in part in Jour. Roy. Micro. Soc., 1911, pp. 703–709, pls. 20–23.

Grinnell, J.

1917. Expedition outfit list: Check-list of equipment and supplies likely to be required on a field trip, compiled from lists of materials used on expeditions made during the past eight years. Univ. Calif. Mus. Vert. Zoöl., 8 pp. [Lists: photographic outfit, general outfit, medical outfit, cook outfit, groceries, and personal supplies. Particularly planned for western U. S. Revised and reprinted, 1934.]

Grosch, P.

1910. Ein Apparat zur Präparation verkieselter Fossilien. Zeitschr. f. prakt. Geol., 18:30–32, 3 figs.

Gross, W.

1934. Die Typen des mikroskopischen Knochenbaues bei fossilen Stegocephalen und Reptilien. Zeitschr. f. Anat., 103:731–764.

Gümbel, C. W.

1873. Untersuchungsart dichter Kalksteine. Neues Jahrb. f. Min. Geol. Pal., Stuttgart, Jhg. 1873:299–304.

Günnell, F. H.

1931. Conodonts from the Fort Scott limestone of Missouri. Jour. Pal., 5:244–252, pl. 29.

Hanna, G. D.

1925. The extraction of fossils from refractory rocks. Jour. Geol., 3: 545–547.

1927. The photography of small objects. Trans. Am. Micro. Soc., 46: 15–25.

1930. Hyrax, a new mounting medium for diatoms. Jour. Roy. Micro. Soc. (ser. 3), 50:424–426.

1931*a*. The adjustment of low power binocular microscopes. Micropaleo. Bull., 3:1–3, 2 figs.

1931*b*. Illustrating fossils. Jour. Pal., 5:49–68, 2 figs. pl. 8.

1937. An illuminator for opaque objects. Jour. Roy. Micros. Soc., 57: 11–14, 2 figs.

HANNA, G. D., and CHURCH, C. C.

1928. Freezing and thawing to disintegrate shales. Jour. Pal., 2:131.

HANNA, G. D., and DRIVER, H. L.

1924. The study of subsurface formations in California oil field development. 10th Ann. Rept. State Oil and Gas Supervisor, Calif. State Mining Bureau, 10:5–26, 10 figs.

HARTMANN-WEINBERG, A., and REINBERG, S. A.

1925. Die fossilhaltigen Gesteinsformationen im Röntgenbilde. Bull. de l'Acad. des Sci. de Russie, 1925:279–292, pls. 1–2. [Results of X-ray photography of limestone and sandstone concretions and shale to determine their fossil content. Material less than 4 cm. thick could be satisfactorily shown with exposures up to 60 sec. in duration.]

HAUFF, BERNHARD

1930. Wie ein Ichthyosaurus das Licht der Welt wieder erblickt. Monatsschr. Württemberg, Jhg. 1930:9–19, 5 figs.

HAY, ALFRED, *et al.*

1930. Photographisches Praktikum für Mediziner und Naturwissenschafter. Vienna: Julius Springer, 1930, x + 531 pp., 299 figs., 3 pls.

HECHT, F.

1933. Arbeitsweisen der Mikropalaeontologie. Senckenbergiana, 15: 346–362.

1934*a*. Einfache Geräte zum Photographieren von Mikrofossilien, insbesondere Foraminiferen. Senckenbergiana, 16.

1934*b*. Eine neue Verteilungszelle zum Aufbewahren von Mikrofossilien, vornehmlich Foraminiferen. Senckenbergiana, 16:152–155.

HENNIG, EDWIN

1932. Wesen und Wege der Paläontologie. Berlin: Gebrüder Borntraeger, iv + 512 pp., illus.

HERMANN, ADAM

1909. Modern laboratory methods in vertebrate palaeontology. Bull. Am. Mus. Nat. Hist., 26:283–331, pls. 52–57, 18 figs.

Holden, F. H.
1914, 1916. A method of cleaning skulls and disarticulated skeletons. Condor, 16:239–241; 18:231.

Holmes, A.
1930. Petrographic methods and calculations. London: Thomas Murby and Co., pp. 231–249.

Hrdlička, Aleš
1904. Directions for collecting information and specimens for physical anthropology. U. S. Nat. Mus. Bull. no. 39, pt. R, 25 pp., 8 pls.

Huene, F. von
1933. Auffindung und Behandlung eines fossilen Saurierskeletts. Aus der Heimat (Naturwissenschaftliche Monatsschrift, Stuttgart), 46:129–135, 10 figs.

Hustedt, Frederick
1929. Vom Sammeln und Präparieren der Kieselalgen sowie Angaben über Untersuchungs- und Kulturmethoden. In Abderhalden, E., Handbuch der biologischen Arbeitsmethoden, Abt. II, Th. 4, 1–99, 33 figs.

Innes, Alberta D.
1927. A description of a simple laboratory apparatus for obtaining accurate tracings of objects. Anat. Record, 36: August 25.

Johannsen, A.
1918. Manual of petrographic methods. 2d ed. New York: McGraw-Hill Book Co., pp. 572–604.

Jurasky, K.
1931. Die Schliffmethoden [und die Mazerationsmethoden] in der Paläobotanik. In Handbuch der biologischen Arbeitsmethoden. Berlin: Urban und Schwarzenburg, 1931, Abt. II, 4:253–284, 6 figs., 1 pl.; 331–352.

Keyes, M. G.
1925. Making thin sections of rocks. Am. Jour. Sci. (ser. 5), 10:538–550.

Kirchheimer, F.
1933. Ueber die Herstellung von Präparaten zur kontrastreichen Wiedergabe fossilen Pollens. Pal. Zeitschr., 15:78–79, 1 pl.

Knight, C. R.
1935. Before the dawn of history. New York: McGraw-Hill Book Co., xiii + 119 pp., 46 pls. [incl. end papers]. [The chapter, "Fossils in relation to man," contains a statement of methods of collection and reconstruction of fossil vertebrates.]

KNOWLTON, F. H.

1927. Plants of the past: a popular account of fossil plants. Princeton: Princeton University Press, xix + 275 pp., 90 figs., and frontis.

KOCH, G.

1913. Ueber Versuche mit Zellon bei zoologischen und paläontologischen Präparationen sowie einige Worte über Gipsabgüsse. Museumskunde, Berlin, 9:216–219.

KOOPMANS, R. G.

1928. Celluloidpräparat anstatt Dünnschliff. Geol. Bur. Nederland. Mijngeb. te Heerlen Jaarversl, 1928:131–132.

KOSLOWSKI, ROMAN

1932. Sur un procédé simple et précis d'effectuer les coupes sérielles des fossiles. Pal. Zeitschr., 13:316–318, 1 fig.

LAHEE, F. W.

1923. Field geology. 2d ed. New York: McGraw-Hill Book Co., xxviii + 651 pp., 457 figs.

LAMBRECHT, KALMAN

1928*a*. Die Verwendung der Fluorographie in der paläontologischen Forschung. Verhl. Zool.-Bot. Ges., Wien, 78:(62)–(70), 3 figs.

1928*b*. Fluorographische Beobachtungen an den "Elastischen Fasern" des Pterosaurier-Patagiums. Arch. Mus. Teyler., 6:40–50, 2 pls.

LANG, W. D.

1930. Paleontology and the public: a curator's aspirations. Proc. Geol. Assoc., 41:175–179, 1 fig.

LECLERQ, S.

1933. Application de lumière infra-rouge à l'étude microscopique des végétaux fossiles. Ann. Soc. Géol. Belgique, vol. 56, sec. B, pp. 351–356, 3 pls.

LEHMANN, W. M.

1934. Röntgenuntersuchung von Asteropyge sp. Broili aus dem rheinschen Unterdevon. Neues Jahrb. Min. Geol. Pal., 72(B):1–14, 2 figs., 1 pl.

1937. Neue Entdeckungen in alter Museumsschätzen. Röntgendurchleuchtung von Versteinerungen des Hunsrückschiefers. Die Umschau, 25:1–5 [of reprint], 8 figs.

LITTLE, E. O.

1903. A method of preparing sections of cancellous bone. Jour. Applied Micros. and Lab. Methods (Rochester, N. Y.), 6:2254–2255, 1 fig.

LOOMIS, F. B.

1936. Are conodonts gastropods? Jour. Pal., 10:663–664, 1 fig.

Lucas, Frederic A.
1914. The preparation of skulls and skeletons for museum purposes. Proc. Am. Assoc. Museums, 8:151–159.

Mann, Albert
1922. Suggestions for collecting and preparing diatoms. Proc. U. S. Nat. Mus., 60:1–8.

Mann, L. M.
1933. Preservation of fossil bones. Nature, 131:366. [Advocates soaking in Gum Dammar.]

Marchionna, F.
1933. Latex and its industrial applications. New York: Rubber Age Publishing Co., 1933, xxiii + 1037 pp.

Mason, H. L.
1934. Pleistocene flora of the Tomales formation. Pt. 4 of Carnegie Instn. Wash. Publ. no. 415 (Studies of the Pleistocene paleobotany of California), pp. 81–179, 1 fig., 11 pls.

Matthew, W. D.
1925. The care and preservation of fossil mammals. MS, Matthew Library, Univ. Calif. Mus. Pal. [Read before the Am. Soc. Mammalogists, 7th ann. mtg., April 10, 1925.]

Mehl, M. G.
1921. Some suggestions for photographing fossils. Science (n.s.), 54:358.

Mercier, Jean
1929. Application des empreintes à la celluloidine pour l'étude des Echinodermes fossiles. Bull. Soc. Linn. Normandie, 1:129–132 (Trav. orig.).

Merrill, G. P.
1895. Directions for collecting rocks and the preparation of sections. U. S. Nat. Mus. Bull. no. 39, pt. I, 15 pp., 7 figs.

Miethe, A., and Born, A.
1928. Die Flurographie von Fossilien. Pal. Zeitschr., 9:343–356, 6 pls.

Miller, S. A.
1889. North American geology and paleontology for the use of amateurs, students and scientists. Cincinnati, Ohio: James Barclay, [1] + 664 pp., 177 figs.

Moodie, R. L.
1915. Some methods of studying fossil Amphibia embedded in coal. Kansas Univ. Sci. Bull., 9:187–193, 3 figs., pl. 1.

Möskes, A.

1931. Ueber die Fluoreszenz und Phosphoreszenz der Fossilien. Naturw. Monatschr. f. die USW. Unterricht, 11:167–170. Berlin, Leipzig.

Moysey, L.

1908. On a method of splitting ironstone nodules by means of an artificial freezing mixture. Geol. Mag. Lond., 5:220–222.

Murata, K. J.

1935. A neglected method for making thin sections of fossils. Jour. Paleo., 9:359–361. [Cutting is done with a thin copper wire and carborundum powder.]

Murray, J., and Renard, A. F.

1891. Rept. Voy. H. M. S. Challenger: Deep Sea Deposits, 1891:257–258, figs. 19–21.

Neblette, C. B.

1935. Photography, its principles and practice. 2d ed. New York: D. Van Nostrand, xxii + 615 pp., illus.

Nopsca, F. von, and Heidsieck, E.

1933. Histology of ribs in immature and half grown trachodont dinosaurs. Proc. Zoöl. Soc. London, 1933:221.

1934. Ueber eine pachyostotische Rippe aus der Kreide Rügens. Acta Zool., 15:431–455, 13 figs.

Peck, R. E.

1934. The North American trochiliscids, Paleozoic Charophyta. Jour. Pal., 8:83–119, pls. 9–13.

Peyer, Bernhard

1931. Die Triasfauna der Tessiner Kalkalpen. II. *Tanystropheus longobardicus* Bass. sp. Abh. Schweiz, Pal. Ges., 50:7–110, 14 pls., 28 figs. [See also Centralbl. Min. Geol. Pal., Abt. B., Jhg. 1930: 336–337.]

1934. Ueber die Röntgenuntersuchung von Fossilien, hauptsächlich von Vertebraten. Acta Zool., lib. 15, fasc. 4–5, pp. 364–379, 2 figs., pls. 51–52.

Poller, Alphons

1931. Das pollersche Verfahren zum Abformen an Lebenden und Toten sowie an Gegenständen.... Berlin und Wien: Urban und Schwarzenberg, 216 pp. [Describes the casting compounds, "Negocoll," "Hominit" and "Celerit," and their use.]

Post, Lennart von

1933. On improvements of the pollen-analysis technique. Geol. Fören. Förhand, 55:523–527.

Prokhorov, M. G.
1929. [Instructions for excavating, preparing, and mounting fossil vertebrates.] Acad. Sci., U. S. S. R., Geol. Mus. Leningrad, 1929:1–75, 6 figs., 7 pls. [In Russian.]

Radley, E. G.
1929. The preservation of pyritised and other fossils. The Naturalist, London, 1929:143–146, 167–173, 196–202.

Radley, J. A., and Grant, Julius
1933. Fluorescence analysis in ultra-violet light. New York: D. Van Nostrand, xi + 219 pp., illus. [Pp. 156–157, note on study and photography of fossils by ultraviolet fluorescence.]

Rathgen, F.
1915. Die Konservierung von Altertumsfunden. I. Teil: Stein und steinartige Stoffe. Handb. k. Mus. Berlin, 153 pp., 91 figs.

Reeside, J. B., Jr.
1930. The preparation of paleontologic illustrations. Jour. Pal., 4: 299–308, 1 pl.

Ridgway, J. L.
1920. The preparation of illustrations for reports of the United States Geological Survey with brief descriptions of processes of reproduction. Dept. of the Interior, U. S. Geol. Survey, Wash., D. C., 101 pp., 11 figs., 9 pls. [Distributed by the Superintendent of Documents.]

Rogers, A. F.
1924. Mineralogy and petrography of fossil bone. Bull. Geol. Soc. Am., 35:535–556, 4 pls.

Rogers, A. F., and Kerr, P. F.
1933. Thin section mineralogy. New York: McGraw-Hill Book Co. [Methods, pp. 3–7.]

Ross, C. S.
1924. A method of preparing thin sections of friable rocks. Am. Jour. Sci. (ser. 5), 7:483–485.
1926. Methods of preparation of sedimentary materials for study. Econ. Geol., 21:454–468.

Rowe, A. W.
1896. The preparation and mounting of chalk fossils. Nat. Sci. London, 9:303–311.

Ruedemann, R., and Goldring, W.
1931. Some museum methods developed in the New York State Museum [Albany]. New York State Mus. Bull., 288:71–83, 8 pls.

Salinas, ———
1897. Sulle Esterie del Trias di Silicia. Mus. Geol. e. Min. R. Univ. Palermo, 1897:5–11, pl. 1.

Schaffer, J.

1893. Die Methodik der histologischen Untersuchungen des Knochengewebes. Zeitschr. Wiss. Mikros. Braunschweig, 10:167–211 (168–173).

Schaffer, R. J., and Hirst, P.

1930. The preparation of thin sections of friable and weathered materials by impregnation with synthetic resin. Proc. Geol. Assoc. London, 41:32–43. [Instead of Canada balsam, a mixture of "Formol," "Phenol," and "Metacresol," in proportions of 6:3:3, is recommended.]

Scheffen, W.

1934. Ein Universaltisch zum Auslesen von Foraminiferen in transparente Zellen. Senckenbergiana, 16:304–308.

Schelenz, M., and Frentzen, K.

1929. Zwei Abformverfahren für palaeontologische und prähistorische Objekte. Centralbl. Min. Geol. Pal., Abt. B, 89–94, 3 figs.

Schlossmacher, K.

1919. Ein Verfahren zur Herrichtung von schiefrigen und lockeren Gesteinen zum Dünnschleifen. Centralbl. f. Min. Geol. Pal., Jhg. 1919:190–192, 1 fig.

Schmidt, Hermann

1934. Conodonten-Funde in ursprünglichem Zusammenhang. Pal. Zeitschr., 16:75–85, 8 figs., pl. 6.

Schuchert, Charles

1895. Directions for collecting and preparing of fossils. Bull. U. S. Nat. Mus. no. 39, pt. K, 1–31, 13 figs.

Secrist, M. H.

1934. Technique for the recovery of Paleozoic arenaceous foraminifera. Jour. Paleo., 8:245–246.

Seegert, Bruno

1929. Fluoreszenzphotographie von Fossilien. Umschau, 32:134–136, 6 figs.

Seitz, L.

1907. Vergleichende Studien über den mikroskoposchen Knochenbau fossiler und rezenter Reptilien. Nov. Acta Leopold., Halle, 137: 231–267, 14 pls.

Seitz, O., and Gothan, W.

1928. Paläontologisches Praktikum. Berlin: Julius Springer, iv + 173 pp., 48 figs.

Simpson, G. G.

1933. A simplified serial sectioning technique for the study of fossils. Am. Mus. Novit., no. 634, pp. 1–6, 1 fig.

1934. Attending marvels: a Patagonian journal. New York: The Macmillan Co., xiii + 295 pp., 15 illus. and a map.

1937. How fossils are collected. Nat. Hist. [Am. Mus., N. Y.], 39: 329–333, 17 figs.

Sollas, W. J.

1903. A method for investigation of fossils by serial sections. Philos. Trans. Roy. Soc. London (Ser. B), 196:259–265, 2 figs.

Spitta, E. J.

1920. Microscopy. 3d ed. London: John Murray, i–xxviii + 538 pp., 255 figs., 28 pls.

Stauffer, C. R.

1933. Middle Ordovician Polychaeta from Minnesota. Bull. Geol. Soc. Am., 44:1173–1218, pls. 59–61.

Steen, Margaret C.

1931. The British Museum collection of Amphibia from the middle Coal Measures of Linton, Ohio. Proc. Zoöl. Soc. London, 1930 [1931]:849–891, 21 figs., pls. 1–6.

Stelzner, A. W.

1890. Ueber die Isolierung von Foraminiferen aus dem Badener Tegel mit Hilfe von Jodidlösung. Ann. k.k. nat.-hist. Hof-Mus. Wien, 5:15–19.

Stensiö, E. A:son

1927. The Downtonian and Devonian vertebrates of Spitsbergen. Pt. I. Family Cephalaspidae. Skrifter om Svalbard og Nordishavet, nr. 12 [Oslo], xii + 391 pp., 103 figs., 112 pls. [Indispensable as a guide to methods of microdissection and microillustration of fossils.]

Sternberg, C. H.

1931. The life of a fossil hunter. 2d ed. San Diego, Calif.: Jensen Printing Company, xiii + 286 pp., 47 figs. [1st ed., 1909.]

1932. Hunting dinosaurs in the badlands of the Red Deer River, Alberta, Canada: a sequel to the Life of a fossil hunter. 2d ed. San Diego, Calif.: Published by the author, xv + 261 pp., 61 figs. [1st ed., 1917.]

Stibbe, E. P.

1930. An introduction to physical anthropology. London: Edward Arnold, vi + 199 + 8 pp., 42 figs., map. [Gives methods of taking measurements of skulls.]

Strasser, H.

1887. Ueber die Methoden der plastischen Reconstruction. Zeitchr. f. Wiss. Mikros. und Mikros. Technik, Bd. 4, Hfte. 2 and 3, pp. 1–50, 6 figs.

Stromer, Ernst

1920. Paläozoologisches Praktikum. Berlin: Gebrüder Borntraeger, vi + 104 pp., 6 figs., bibliog.

Strunz, C.

1928. Aus der Werkstatt des Präparators. 2. Die Präparation eines Pleurosaurus-skeletts. Ber. Senck. Naturf. Ges., Frankfurt a. M. (Natur u. Museum), 58:116–121, 6 figs. [See also Natur u. Mus., 11:534.]

Swinton, W. E.

1933. Bakelite and the preservation of fossils. (British Mus. Nat. Hist.) The Museum's Journal, 33:76–80. [Copies may be obtained from the Bakelite Corporation, 247 Park Ave., N. Y. Nicols and Orr (*op. cit.*, 32:47–53) give an account of the use of "Bakelite" in the preservation of fossil bones and some of the methods and apparatus used by them.]

Taeger, H.

1930. Zur Wiederherstellung zerbrochener Schädel mit besonderer Berücksichtigung der Weinert'schen Zussammensetzung des Schädels von Le Moustier. Zeitschr. Morphol. Anthropol., 28: 313–344.

Thompson, I. M.

1924. A simple improvised dissecting microscope. Anat. Rec., 34: 37–40, 1 fig.

Tornquist, A.

1910. Die in der kgl. Universitäts-Bernsteinsammlung eingeführte Konservierungsmethode für Bernsteineinschlüsse. Schrift. physik.-okonom Ges., Königsberg Pr., 51:243–247. [See also pp. 216–233.]

Twenhofel, W. H.

1926. Treatise on sedimentation . . . Baltimore: The Williams & Wilkins Co., xxv + 661 pp., 61 figs.

Udluft, Hans, and Matern, Hans

1926. Ein Beitrag zur Präparation von verkiesten Fossilien. Senckenbergiana, 8:17–22, 3 figs.

Ulrich, E. O., and Bassler, R. S.

1926. A classification of the toothlike fossils, conodonts, with descriptions of American Devonian and Mississippian species. Proc. U. S. Nat. Mus., 68:1–63, 11 pls.

Van Heurck, Henry

1896. A treatise on the Diatomaceae. London, 558 pp., 35 pls., 291 figs.

Voigt, Ehrhard

1933. Die Uebertragung fossiler Wirbeltierleichen auf Zellulose-Filme, eine neue Bergungsmethode für Wirbeltiere aus der Braunkohle. Pal. Zeitschr., 15:72–78, 3 figs.

1936. Die Lackfilmmethode, ihre Bedeutung und Anwendung in der Palaeontologie, Sedimentpetrographie und Bodenkunde. Zeitschr. deutsch. Geol. Gesell., 88:272–292, 3 pls.

Wagner, Ernst

1928*a*. Zur Fluorographie von Fossilien. Ein neuer und einwandfreier Glasfilter. Pal. Zeitschr., 10:298.

1928*b*. Zur Priorität der UV- Untersuchung von Fossilen. Pal. Zeitschr., 10:215.

Walkhoff, O.

1901. Die normale Histologie menschlicher Zähne einschliesslich der mikroskopischen Technik. Leipzig, pp. 150–161.

Walther, Johannes, and Weigelt, Johannes

1931. Die eozäne Lebewelt in der Braunkohle des Geiseltals. Kaiserlich. Leopold. deutsch. Akad. Naturforsch. Halle, 1931 (= Acta Acad. Leop.-Carol. [n.s.], Bd. 1, 1932; = Mitt. Geol. Pal. Inst. Univ. Halle, no. 64), pp. 1–27. [Pp. 23–26 deal with methods of collection and preparation. See also Weigelt, 1931.]

Walton, L. B.

1907. Contributions to museum technique. I. Cataloguing museum specimens. Am. Nat., 41:77–96, 3 figs.

Weigelt, Johannes

1931. Ueber ein Leichenfeld in der Mittelkohle der Braunkohlengrube Cecilie im Geiseltal <Mitteleozän>. Paleobiologica, 4: 49–78, 1 fig., 1 pl. [Pp. 72–77 deal with the special methods of excavation and preparation of delicate material from the soggy brown-coal. See also Walther and Weigelt, 1931.]

Wentworth, C. K.

1925. Photographic practice for field geologists. Univ. Iowa Studies (n.s.), no. 89; Studies in Nat. Hist., 11:17–41, 5 pls.

Wentworth, C. K., and Suzuki, F. T.

1936. Multiple grinding of thin-section chips. Am. Jour. Sci., 31: 93–96, 1 fig.

Weston, W. H.

1935. The use of celluloid in botanical illustrations. Am. Jour. Botany, 22:384–391, 3 figs.

Weymouth, A. A.

1928. Simple methods for making thin sections. Econ. Geol., 23:323–330.

White, C.

1891. A new method of infiltrating osseous and dental tissues. Jour. Roy. Mikros. Soc. London, 1:307–308.

Williams, S. R.

1917. Scientific drawing in biology. Ohio Jour. Sci., 17:205–212.

Wiman, C.

1895. Ueber die Graptolithen. Bull. Geol. Inst. Upsala, 2:15–22. [See also Nat. Sci., vol. 9.]

Wulff, R.

1916. Ein Beitrag zur Präparation fossiler Korallen. Centralbl. f. Min. Geol. Pal., Stuttgart, Jhg. 1916:445–446.

INDEX

Abrasives, 37, 130, 136
Accession catalogue, 55
Acids, 31, 38, 117
Adhesives, 17, 32, 84, 90
Agitators, 99
Algae, 93, 94, 140
Alkalies, 87, 101, 119, 134
Aloxite, 136
Alum water, 44
Amber, 73
Ambroid, 32
Ammonium chloride for fuming, 45, 50
Amyl acetate, 31
Asphalt, removing, 73
Automatic drills, 36
Awls, scrapers, and scratchers, 9, 29

Bakelite, 34, 63, 84, 90, 133
Bandaging methods, 10, 82
Beeswax, in excavating, 19; for serial sections, 54
Benzene, 19
Blotting-paper casts, 46
Bone, structure of, 73, 138, 143
Bromoform technique, 106
Brushes, 9, 29, 31
Burris India-ink technique, 137

Cabellero technique, 124, 135
Camera lucida, 47
Camp cookery, xxii
Canada-balsam technique, 39
Carborundum, 37, 130, 143
Card-index catalogues, 55
Casting methods, 41, 46, 91
Cataloguing, 55
Celerit, 46
Celloidin-peel methods, 53
Cellophane, for serial sections, 54
Cellulose, test for, 74
Cellulose acetate (celluloid), 19, 31, 32, 49, 53
Charophyta, 94
Chemicals, etc., used in preparation, 31
Chinese pick, 9
Chisels, 29, 30, 72, 88
Chitin, preparation of, 39; tests for, 74
Coal, fossils in, 39, 52, 142
Coccospheres, 93
Conodonts, 130
Corals, 149
Corrosive sublimate, 33, 45
Crushing apparatus, 96
Crystallization, for disintegration, 101

Demovit, 17
Dental plaster, 44, 46
Dental tools, 29, 36
Dextrin, in plaster, 42
Diamond saws, 38, 52
Diatomite, 92
Diatoms, 117, 148
Dioptograph, 40, 47
Disintegrators, 98, 118
Distortion in drawings, 47
Drawing, 47
Drills, 31, 32
Dupont cement, 32
Durol, 17, 34
Dynamite, use of, 9

Electroplated casts, 46
Excavating methods, 1, 5
Exhibition cases, 65, 71
Exhibits, 60
Expeditions, outfits for, xvii
Exploration, xvi

Field work, 1
Fish scales, 127
Flotation and decantation, 104, 105, 106, 119, 131
Flour paste, 12
Foraminifera, 94, 95, 117, 125
Fossils: defined, xi; occurrence of, 3; recognition of, 2; search for, 4
Fossil wood, 52, 72, 73
Freezing technique, 101
Fresno scrapers, 6

Glue, 33
Glue casts, flexible, 45
Glue molds, 41
Grass seeds, collecting, 72
Grinding laps, 125
Grinding wheels, 37
Gum arabic, 17, 31
Gum Dammar, 142
Gum plaster, 33
Gutta-percha molds, 46

Habitat groups, 63, 65
Hammers, 9, 31, 88
Hardening fluids, 17, 32, 44, 84, 90
Hauff scrapers, 29
History of fossil collecting, xv
Hominit, 46
Horn, test for, 74
Hydrocal, 41
Hydroxides, 87, 101, 119, 126
Hypo-acetine, 39
Hyrax, 123, 135, 139

Illuminators, 112
Infrared photography, 51
Insects, 19, 73
Ivory tusks, preservation of, 60

Jacketing, 10
Japanese chisels, 30

Keene's cement, 33
Keratin, test for, 74
Kollolith, 39

Labels, 58, 70
Laboratory equipment, 31; technique, 28
Lamps, for microscopic work, 111
Lard oil, 32, 41
Latex molds, 45
Leaves, handling of, 53, 72
Limestone, fossils in, 86
Liquid soap, 41
Locality data, 24, 57

Maceration, 73, 126
Macrofossils, invertebrate, 79
Mapping, 10
Microfossils, 91
Microphotography. *See* photomicrography
Microscopic technique, 39, 73, 104, 107, 109, 121, 126
Mikah casting gelatin, 42, 45
Mills, for disintegration, 99
Modeling, 40
Modeling clay, 31, 42, 91
Motors, 31, 36
Moto-Tool, 37
Mounting large skeletons, 63; microfossils, 39, 104, 107, 109, 121
Moving pictures, 65
Museum catalogues, 55; methods, 55, 60

Needles, 9, 29, 38
Negative photographs, 39, 50
Negocoll, 46
Notebook data, 24, 79
Numbering specimens, 24
Numerical catalogue, 57

Occurrence of fossils, xiii, 24, 80
Ostracoda, 95
Otoliths, 127
Ovens, 89, 90, 96
Oxyacetylene flame, for preparation, 39, 89

Paleobotanical methods, xii, 19, 52, 72–74, 94, 117, 123, 126
Panel mounts, 65
Pantograph, 40, 47
Papier-mâché, 41, 63
Paraffin: in excavating, 22; in casting, 46; for serial sections, 54; as a preservative, 133
Peat and lignite, xv, 19
Permits for fossil collecting, 26
Photography, xxi, 39, 49
Photomicrography, 48
Piano wire, in mounting, 63
Picks, 9, 88
Piecing and mending, 4, 32
Plasteline, 40
Plaster of Paris, 12, 41, 83
Plastics, 12, 31, 33, 39–46, 63, 83, 91
Plug-and-feathering, 23
Pneumatic tools, 36
Pollen, 19, 53, 126, 140
Polychaetes, 130
Preparation, 32, 82
Projection apparatus, 48, 55
Prospecting methods, 1
Pseudofossils, x
Putty, for squeezes, 46
Pyrites disease, 40

Quarrying, 6, 10, 23

Radiolarians, 117
Realgar, 122
Reconstruction methods, 32, 40, 63
Reflux condenser, 101
Refractive oils, 38, 49, 132
Resin for impregnation, 34
Rhabdospheres, 93
Rice paper, 16
Rock matrices, treatment of, xiv, 80, 96

Sand blast, use of, 87
Sandpaper, 31
Sandstone, fossils in, 85
Screening methods, 83, 102
Sectioning and polishing, 52, 124, 145
Separatory funnels, 106
Serial sectioning, 53, 134
Shale, fossils in, 83, 96
Shellac, 9, 10
Shipping crates and boxes, 22, 27
Silicoflagellates, 123
Silicosis, 37
Skeletons, preparing, 39, 69
Soft parts, remains of, 19, 33, 51, 74
Solvents, 19, 31, 38, 73, 87, 101, 117, 119
Squeezes and molds, 39, 46
Steel wool, uses of, 31, 39
Stensiö's photographic methods, 49
Storage, 58
Talcum powder, 44, 91
Trochiliscids, 94
Terra-cotta casts, 41
Tools, excavating, 9; laboratory, 28
Tracks, casting of, 46
Transportation, methods of, xvii, 15
Tuff, fossils in, xiv, 87
Tunicin, test for, 74
Type specimens, care of, 59
Ultraviolet photography, 50
Volcanic rocks, fossils in, 87
Water glass, 32
Welding, 60
Wire brushes, 31, 134
Wood, structure of, 73
Wrapping and packing, 5, 23, 27, 82, 95
X-ray photography, 52, 139

W8-AUB-124